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EFFECT OF SELF-LOCKING NUTS ON TORQUE-TENSION RELATIONSHIP

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Testing was conducted to determine torque-tension relationship for self-locking nuts. The test results indicated that torque wrench method is not accurate for determining preload when fasteners are preloaded to 75-80 percent of their ultimate tensile strength. The accuracy of torque wrench method deteriorates even more if fasteners are used for more than one cycle application. There was also significant difference in preload between all metal nuts and nuts with nonmetallic insert. The fastener preload → over

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variation decreased with larger fasteners.

SUMMARY

Testing was conducted by the Naval Air Development Center to determine torque-tension relationship for selected self-locking nuts. The torque wrench and Skidmore-Wilhelm bolt tension tester were used in determining torque-tension relationship.

The control of fastener preload is necessary in the design of rigid joints for Navy aircraft, since joint strength is effected by preload as well as by tensile strength of the fastener. The proper amount of preload will not only extend the joint and fastener fatigue life but will also increase the structural reliability.

The test results indicated that torque wrench method is not accurate for determining preload when fasteners are preloaded to 75-80 percent of their ultimate tensile strength. The accuracy of torque wrench method deteriorates even more if fasteners are used for more than one cycle application. There was also significant difference in preload between all metal nuts and nuts with nonmetallic inserts. The fastener preload variation decreased with larger fasteners.

Based on the test results it is recommended that fasteners should not be reused when they are preloaded to 75-80 percent of the fastener ultimate tensile strength by torque wrench method.

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INTRODUCTION

The testing program to determine torque-tension relationship for selected threaded fasteners was conducted by the Naval Air Development Center (NAVAIRDEVCEN) under AIRTASK A510-5103/001-4/3510-000-002, Work Unit A5303-59.

Due to the continual naval aircraft service problems created by the lack of realistic torque values for threaded fasteners the Naval Air Systems Command requested that a study be made and testing conducted by this Center to determine torque-tension relationship that could provide realistic torque values for selected threaded fasteners.

The control of fastener preload is necessary in the design of rigid joints for Navy aircraft, since joint strength is effected by preload as well as tensile strength of the fastener. The proper amount of preload will extend the joint and fastener fatigue life thereby increasing the structural reliability of the system. Exact preload is difficult to obtain due to variables such as; bolt and nut friction, bearing area friction, bolt and nut dissimilar materials having different anti-seize properties, thread tolerances, hardness, alignment, type of finish, coating, lubricant and age of lubricant. There are a number of different methods that can be used to control preload of threaded fasteners, some of them are listed below in order of increasing accuracy:

1. Feel method - preload is determined by feel.

2. Torque wrench method - the nut or bolt is turned to a predetermined torque.

3. Turn-of-nut method - the nut or bolt is turned a predetermined number of degrees after all play has been removed from the joint.

4. Preload indicating washer method - utilizes compression of an inner ring between two flat washers with an outer indicating washer for control. As the load increases, the inner ring (which is higher than the outer indicating washer) is sqeezed down and is enlarged in diameter; the predetermined preload is obtained when the outer indicating washer binds against the two flat washers. The other type of indicating washer utilized collapse of washer's precision collar when predetermined preload has been reached.

5. Frangible nut (collar shear-off) method - utilizes collar on the nut that shears-off at a predetermined preload.

6. Pull method - the pin is stretched to a predetermined load with a tool while the collar is swaged into the groove of the pin or threaded on to the pin.

7. Bolt elongation method - preload is determined by measuring the acutal change in the length of the bolt.

8. Strain gage method - preload is determined by use of strain gages.

NAVAIRDEVCEN evaluated method 2 (torque wrench method), and used the preload of 80 percent of the fastener ultimate tensile strength in this evaluation, since this is an optimum preload for torque wrench method. This method is very inexpensive and has been widely accepted by the aircraft industry. A Snap-on torque wrench was used to determine the torque and Skidmore-Wilhelm bolt tension tester was used to determine the tension.

DESCRIPTION OF TEST SAMPLES

The alloy steel self-locking nuts used in test program were MS21042, MS21044, MS21045 and MS21245. Half of the nuts from each military standard had a dry film lubricant and the other half a soluble lubricant, and were obtained from the Defense Industrial Supply Center (DISC).

The MS21042 nuts were of designs A and B and are shown in figure 1, their locking element consisted of upper threaded section being elliptically offset. The MS21044 nuts were of design C and are shown in figure 2, their locking element consisted of nonmetallic insert. The MS21045 nuts were of designs G, H, E and F and are shown in figure 3. The locking element of designs G and H consisted of upper threaded section being divided into six equal segments which were upset or closed in. The locking element of designs E and F consisted of upper threaded section being elliptically offset. The MS21245 nuts were of design K and are shown in figure 4, their locking element consisted of upper threaded section being divided into six equal segments which were upset or closed in. The nuts of designs D and J are shown in figures 3 and 4 but were not used in this evaluation. The nuts were tested on MS21250, MS20004, MS20005, MS20006 and MS20008 bolts, with exception of MS21250 the bolts were of 160 KSI Ftu strength level. The MS21250 bolts were of 180 KSI Ftu strength level and were used for No. 10 size, since this size is not available in 160 KSI Ftu strength level. The MS20002 countersunk washers were used under bolts and nuts bearing areas.

DESCRIPTION OF TEST AND SETUP

The bolts and nuts with countersunk washers under the bearing areas were installed in 30,000 pounds Skidmore-Wilhelm bolt tension tester, which had two gages, one of 10,000 pounds and the other 30,000 pounds. The nut was then turned while the bolt was held stationary. This procedure was repeated for 5 cycles. The nuts were preloaded to approximately 80 percent of the nut minimum ultimate tensile strength. The torque needed to obtain this preload was established by tests on initial samples and was not varied for the nuts of the same size and strength level, regardless of the nut design or preload. The torque readings were obtained by using 300 in.-lbs., 600 in.-lbs. and 250 ft.-lbs. Snap-on torque wrench and preload readings were obtained from gages on Skidmore-Wilhelm bolt tension tester.

SUMMARY OF RESULTS

The torque-tension relationship (figures 5 through 30) between various self-locking element designs, lubricants and even between samples of the same

design and size exhibited marked differences. The comparative torque-tension relationship, preload spread and variation between samples of different designs and lubricants are shown in figures 31 through 47 and in tables I through V. The effect of friction factor (coefficient of friction) on torque-tension relationship are shown in figures 48 through 52. Due to wide preload spread obtained on the fifth cycle, see tables I through V, results beyond first cycle could not be evaluated in detail. The differences in the preload among the samples for the first cycle (at the torque which was initially determined by test to be 80 percent of the nut minimum ultimate axial strength) are detailed below:

1. MS21042 (first cycle with dry film lubricant).

Sizes No. 10, 1/4, 5/16 and 3/8 inch were of design B, B, A and A respectively, see figure 1. The preload spreads on five samples of each size were: 36, 19, 8 and 17 percent for sizes No. 10, 1/4, 5/16 and 3/8 inch respectively. Sample nuts of sizes No. 10 and 1/4 inch were from 32 percent below to 21 percent above the 80 percent preload, see tables I and II. Sample nuts of sizes 5/16 and 3/8 inch were 51 to 11 percent below the 80 percent preload, see tables III and IV.

2. MS21042 (first cycle with soluble lubricant).

Sizes No. 10, 1/4, 5/16 and 3/8 inch were of design B, see figure 1. The preload spreads on five samples of each size were: 29, 53, 13 and 18 percent for sizes No. 10, 1/4, 5/16 and 3/8 inch respectively. Sample nuts of size 1/4 inch were from 24 percent below to 29 percent above the 80 percent preload, see table II. Sample nuts of sizes No. 10, 5/16 and 3/8 inch were 68 to 6 percent below the 80 percent preload, see tables I, III and IV.

Based on sample average of sizes No. 10, 1/4, 5/16 and 3/8 inch the average friction factor (coefficient of friction) for nuts with dry film lubricant was 0.21 and for nuts with soluble lubricant was 0.25, see table VI.

3. MS21044 (first cycle with soluble lubricant and nonmetallic insert).

Sizes No. 10, 1/4, 5/16, 3/8 and 1/2 inch were of design C, see figure 2. The preload spread on five samples of each size were: 80, 54, 39, 25 and 39 percent for sizes No. 10, 1/4, 5/16, 3/8 and 1/2 inch respectively. Sample nuts of sizes No. 10 and 1/4 inch were from 63 percent below to 17 percent above the 80 percent preload, see tables I and II. Sample nuts of sizes 5/16, 3/8 and 1/2 inch were 62 to 4 percent below the 80 percent preload, see tables III, IV and V.

Based on sample average of sizes No. 10, 1/4, 5/16, 3/8 and 1/2 the average friction factor (coefficient of friction) for nuts was 0.30, see table VII.

4. MS21045 (first cycle with dry film lubricant).

Sizes No. 10, 1/4, 5/16, 3/8 and 1/2 inch were of design E, G, F, H and H respectively, see figure 3. The preload spreads on 5 samples of each size were: 23, 23, 25, 18 and 40 percent for sizes No. 10, 1/4, 5/16, 3/8 and 1/2 inch respectively. Sample nuts of sizes No. 10 and 3/8 inch were from 17 percent below to 9 percent above the 80 percent preload, see tables I and IV. Sample nuts of size 1/4 inch were 24 to 1 percent below the 80 percent preload, see table II. Sample nuts of sizes 5/16 and 1/2 inch were 13 to 53 percent above the 80 percent preload, see tables III and V.

5. MS21045 (first cycle with soluble lubricant).

Sizes No. 10, 1/4, 5/16, 3/8 and 1/2 inch were of design E, E, G, E and F respectively, see figure 3. The preload spreads on five samples of each size were: 46, 38, 58, 8 and 23 percent for sizes No. 10, 1/4, 5/16, 3/8 and 1/2 inch respectively. Sample nuts of sizes No. 10 and 1/2 inch were from 9 percent below to 37 percent above the 80 percent preload, see tables I and V. Sample nuts of size 3/8 inch were 36 to 28 percent below the 80 percent preload, see table IV. Sample nuts of size 1/4 and 5/16 were 19 to 65 percent above the 80 percent preload, see tables II and III.

Based on sample average of sizes No. 10, 1/4, 5/16, 3/8 and 1/2 inch the average friction factor (coefficient of friction) for nuts with dry film lubricant was 0.20 and for nuts with soluble lubricant was 0.18, see table VIII.

6. MS21245 (first cycle).

Nuts with dry film and nuts with soluble lubricant were of 1/2 inch size and of design K, see figure 4. The preload spread on five samples with dry film lubricant was 28 percent and for samples with soluble lubricant was 34 percent. The preload spread on sample nuts with dry film lubricant varied from 2 to 30 percent above, and on samples with soluble lubricant from 15 percent below to 19 percent above the 80 percent preload, see table V.

Based on sample average of one size the average friction factor (coefficient of friction) for nuts with dry film lubricant was 0.14 and for nuts with soluble lubricant was 0.16, see table IX.

Preload for the fifth cycle varied widely and the extreme variations are listed below:

1. MS21042 (fifth cycle with dry film lubricant).

a. Size No. 10, 1900 to 2900 pounds for the first cycle and 700 to 3400 pounds for the fifth cycle.

b. Size 3/8, 6000 to 10800 pounds for the first cycle and 3850 to 10,000 pounds for the fifth cycle.

2. MS21042 (fifth cycle with soluble lubricant).

a. Size No. 10, 1800-2600 pounds for the first cycle and 3800 pounds for the fifth cycle for one sample only because bolts broke on other four samples before required torque was reached.

b. Size 5/16, 2500 to 3500 pounds for the first cycle and 2100 to 6750 pounds for the fifth cycle.

3. MS21044 (fifth cycle with soluble lubricant and nonmetallic insert).

a. Size 3/8, green insert, 3125 to 4750 pounds for the first cycle and 11625 to 12750 pounds for the fifth cycle.

b. Size 3/8, red insert, 3055 to 5800 pounds for the first cycle and 11375 pounds for the fifth cycle for one sample only, because nut thread stripped on other four samples before required torque was reached.

4. MS21045 (fifth cycle with soluble lubricant).

a. Size 1/4, 4375 to 5750 pounds for the first cycle and 2375 to 2750 for the fifth cycle.

b. Size 3/8, 5875 to 7500 pounds for the first cycle and 4750 to 12375 for the fifth cycle.

5. MS21045 (fifth cycle with dry film lubricant).

a. Size 1/4, 2800 to 3625 pounds for the first cycle and 1750 to 2375 for the fifth cycle.

b. Size 3/8, 7600 to 9250 pounds for the first cycle and 9250 to 11250 pounds for the fifth cycle.

6. MS21245 (fifth cycle with soluble lubricant).

a. Size 1/2, 9375 to 13125 pounds for the first cycle and 3000 to 3750 pounds for the fifth cycle.

D I S C U S S I O N

In this test program no attempt was made to determine what effect lubricant age or various locking elements have on preload. The military standards leave the shape of the upper part of the nut and the locking element design optional, therefore, different manufacturers make nuts with various upper shapes and locking elements which meet the same military standard. The self-locking nuts used in this test program were obtained from Defense Industrial Supply Center (DISC) by specifying federal stock number, therefore, they are representative samples as to what is used in the field. The tested nuts had various upper shapes and locking elements, see

figures 1, 2, 3 and 4, and because they were obtained out of stock and lack identification markings, determination could not be made when or who manufactured them.

During torque-tension tests the MS21042-3 all metal nuts and MS21044N6 nuts with red and green nonmetallic inserts had appreciably higher preload on the fifth cycle than on the first cycle, which is contrary to data obtained for the other samples, see figures 9, 16 and 17. The trend of the test data indicates that with each reuse of the fastener, higher torque is needed to obtain the same preload. No explanation can be ade for opposing resul+s on MS21042-3 and MS21044N6.

C O N C L U S I O N S

1. Based on the test results the torque wrench method for determining preload is not accurate.

2. Fasteners that have been preloaded to 75-80 percent of the ultimate tensile strength should not be used beyond first cycle application.

3. The fastener preload becomes more uniform with larger size fasteners.

4. The variation of the friction factor (coefficient of friction) between all metal dry film lubricated nuts and all metal nuts with soluble lubricant was not significant. The friction factors, for the first cycle only, were as follows:

a. Friction factor 0.21 for MS21042 with dry film lubricant.
b. Friction factor 0.25 for MS21042 with soluble lubricant.

c. Friction factor 0.21 for MS21045 with dry film lubricant.
d. Friction factor 0.18 for MS21045 with soluble lubricant.

e. Friction factor 0.14 for MS21245 with dry film lubricant.
f. Friction factor 0.16 for MS21245 with soluble lubricant.

If sizes No. 10 and 1/4 inch were not included in calculating average friction factor for MS 21045, the friction factor for nuts with and without dry film lubricant would be 0.15.

5. There is a significant difference in friction factor between all metal nuts and nuts with nonmetallic insert. The friction factor for nuts with nonmetallic insert was 0.30.

R E C O M M E N D A T I O N S

1. Based on the test results it is recommended that fasteners should not be reused when they were preloaded to 75-80 percent of the fasteners ultimate tensile strength by torque wrench method.

2. It is recommended that when fasteners are preloaded to 75-80 percent

of the fastener ultimate tensile strength the torque wrench method should not be used in application where failure of one fastener would result in failure of the system.

3. Based on the test results it is recommended that friction factor of 0.30 be used for MS21044 self-locking nuts with nonmetallic insert for sizes No. 10 through 1/2 inch and 0.15 for MS21045 self-locking nuts made from alloy steel for sizes 5/16 through 1/2 inch.

4. Additional tests should be conducted to determine accuracy of other methods to control preload of threaded fasteners such as preload indicating washers and frangible nut (collar shear-off nut).

TABLE I. TORQUE-TENSION VARIATION FOR NO. 10 SIZE NUT

Part Number and Size	Sample Design, See Figures 1, 2, 3 or 4	Number of Samples Tested	Torque (in.-lbs.)	Cycle Reading Taken	Nut Min. Axial Strength (lbs.)	75% of the Nut Min. Axial Strength (lbs.)	80% of the Nut Min. Axial Strength (lbs.)	Preload Spread on Tested Samples (lbs.)
MS21042L3	B	5	100	First	3470	2602	2776	1900-2900
MS21042L3	B	5	100	Fifth	3470	2602	2776	700-3400
MS21042-3	B	5	100	First	3470	2602	2776	1800-2600
MS21042-3	B	5	100	Fifth	3470	2602	2776	3800*
MS21044N3	C	5	100	First	2460	1845	1968	725-2300
MS21044N3	C	5	100	Fifth	2460	1845	1968	800-2100
MS21045L3	E	5	100	First	2460	1845	1968	1700-2150
MS21045L3	E	5	100	Fifth	2460	1845	1968	1550-1700
MS21045-3	E	5	100	First	2460	1845	1968	1800-2700
MS21045-3	E	5	100	Fifth	2460	1845	1968	1000-1400

*No data on four samples bolt broke.

TABLE II. TORQUE-TENSION VARIATION FOR 1/4 SIZE NUT

Part Number and Size	Sample Design, See Figures 1, 2, 3 or 4	Number of Samples Tested	Torque (in.-lbs.)	Cycle Reading Taken	Nut Min. Axial Strength (lbs.)	75% of the Nut Min. Axial Strength (lbs.)	80% of the Nut Min. Axial Strength (lbs.)	Preload Spread on Tested Samples (lbs.)
MS21042L4	B	5	250	First	6200	4650	4960	5000-6000
MS21042L4	B	5	250	Fifth	6200	4650	4960	3125-3750
MS21042-4	B	5	250	First	6200	4650	4960	3750-6375
MS21042-4	B	5	250	Fifth	6200	4650	4960	2375-4375
MS21044N4	C	5	250	First	4580	3435	3664	2500-4100
MS21044N4	C	5	250	Fifth	4580	3435	3664	1450-2000
MS21045L4	G	5	250	First	4580	3435	3664	2800-3625
MS21045L4	G	5	250	Fifth	4580	3435	3664	1750-2375
MS21045-4	E	5	250	First	4580	3435	3664	4375-5750
MS21045-4	E	5	250	Fifth	4580	3435	3664	2375-2750

TABLE III. TORQUE-TENSION VARIATION FOR 5/16 SIZE NUT

Part Number and Size	Sample Design, See Figures 1, 2, 3 or 4	Number of Samples Tested	Torque (in.-lbs.)	Cycle Reading Taken	Nut Min. Axial Strength (lbs.)	75% of the Nut Min. Axial Strength (lbs.)	80% of the Nut Min. Axial Strength (lbs.)	Preload Spread on Tested Samples (lbs.)
MS21042L5	A	5	400	First	9820	7365	7856	4625-5250
MS21042L5	A	5	400	Fifth	9820	7365	7856	4000-5375
MS21042-5	B	5	400	First	9820	7365	7856	2500-3500
MS21042-5	B	5	400	Fifth	9820	7365	7856	2100-6750
MS21044N5	C	5	400	First	7390	5542	5912	3350-5700
MS21044N5	C	5	400	Fifth	7390	5542	5912	2300-2750
MS21045L5	F	5	400	First	7390	5542	5912	7500-9000
MS21045L5	F	5	400	Fifth	7390	5542	5912	7900-8500*
MS21045-5	G	5	400	First	7390	5542	5912	6300-9750
MS21045-5	G	5	400	Fifth	7390	5542	5912	2750-7100

*No data one sample threads stripped.

TABLE IV. TORQUE-TENSION VARIATION FOR 3/8 SIZE NUT

Part Number and Size	Sample Design, See Figures 1, 2, 3 or 4	Number of Samples Tested	Torque (in.-lbs.)	Cycle Reading Taken	Nut Min. Axial Strength (lbs.)	75% of the Nut Min. Axial Strength (lbs.)	80% of the Nut Min. Axial Strength (lbs.)	Preload Spread on Tested Samples (lbs.)
MS21042L6	A	5	500	First	15200	11400	12160	6000-10800
MS21042L6	A	5	500	Fifth	15200	11400	12160	3850-10000
MS21042-6	B	5	500	First	15200	11400	12160	6750-9000
MS21042-6	B	5	500	Fifth	15200	11400	12160	3750-7250
MS21044N6 (Green Insert)	C	5	500	First	11450	8588	9160	3125-4750
MS21044N6 (Green Insert)	C	5	500	Fifth	11450	8588	9160	11625-12750
21044N6 (Red Insert)	C	5	500	First	11450	8588	9160	3500-5800
MS21044N6 (Red Insert)	C	5	500	Fifth	11450	8588	9160	11375*
MS21C45L6	H	5	500	First	11450	8588	9160	7600-9250
MS21045L6	H	5	500	Fifth	11450	8588	9160	9250-11250
MS21045-6	E	5	500	First	11450	8588	9160	5875-7500
MS21045-6	E	5	500	Fifth	11450	8588	9160	4750-12375

*No data on four samples threads stripped.

TABLE V. TORQUE-TENSION VARIATION FOR 1/2 SIZE NUT

Part Number and Size	Sample Design, See Figures 1, 2, 3 or 4	Number of Samples Tested	Torque (ft.-lbs.)	Cycle Reading Taken	Nut Min. Axial Strength (lbs.)	75% of the Nut Min. Axial Strength (lbs.)	80% of the Nut Min. Axial Strength (lbs.)	Preload Spread on Tested Samples (lbs.)
MS21245L8	K	5	75	First	13750	10312	11000	11200-14250
MS21245L8	K	5	75	Fifth	13750	10312	11000	6750-10250
MS21245-8	K	5	75	First	13750	10312	11000	9375-13125
MS21245-8	K	5	75	Fifth	13750	10312	11000	3000-3750
MS21044N8	C	5	125	First	21110	15832	16888	9000-13000
MS21044N8	C	5	125	Fifth	21110	15832	16888	8125-14750
MS21045L8	H	5	125	First	21110	15832	16888	19000-25875
MS21045L8	H	5	125	Fifth	21110	15832	16888	16500-19750
MS21045-8	F	5	125	First	21110	15832	16888	16750-20625
MS21045-8	F	5	125	Fifth	21110	15832	16888	11500-18625

TABLE VI. FRICTION FACTOR FOR MS21042 NUTS

Part Number and Size	Sample Type, See Figures 1, 2, 3 or 4	Number of Samples Tested	Torque at which Friction Factor was Determined	Friction Factor Spread (First Cycle) Low	Friction Factor Spread (First Cycle) High	Five Samples Average Friction Factor (First Cycle)	Friction Factor Spread (Fifth Cycle) Low	Friction Factor Spread (Fifth Cycle) High	Five Samples Average Friction Factor (Fifth Cycle)
MS21042L3	B	5	100 in.-lbs.	0.18	0.28	0.23	0.15	0.75	0.30
MS21042-3	B	5	100 in.-lbs.	0.20	0.29	0.26	*	*	*
MS21042L4	B	5	250 in.-lbs.	0.17	0.20	0.18	0.27	0.32	0.30
MS21042-4	B	5	250 in.-lbs.	0.16	0.27	0.18	0.23	0.42	0.33
MS21042L5	A	5	400 in.-lbs.	0.24	0.28	0.25	0.24	0.32	0.26
MS21042-5	B	5	400 in.-lbs.	0.37	0.51	0.40	0.19	0.61	0.40
MS21042L6	A	5	500 in.-lbs.	0.12	0.22	0.16	0.13	0.35	0.17
MS21042-6	B	5	500 in.-lbs.	0.15	0.20	0.16	0.18	0.36	0.24
Average (With and Without Dry Film Lub)				0.20	0.28	0.23	0.20	0.45	0.29
Average (Dry Film Lub Only)				0.18	0.25	0.21	0.20	0.44	0.26
Average (Without Dry Film Lub Only)				0.22	0.32	0.25	0.20	0.46	0.32

*No data on four samples bolt broke, fifth cycle was not used in calculation.

TABLE VII. FRICTION FACTOR FOR MS21044 NUTS

Part Number and Size	Sample Type, See Figures 1, 2, 3 or 4	Number of Samples Tested	Torque at which Friction Factor was Determined	Friction Factor Spread (First Cycle)		Five Samples Average Friction Factor (First Cycle)	Friction Factor Spread (Fifth Cycle)		Five Samples Average Friction Factor (Fifth Cycle)
				Low	High		Low	High	
MS21044N3	C	5	100 in.-lbs.	0.23	0.73	0.34	0.25	0.66	0.45
MS21044N4	C	5	250 in.-lbs.	0.24	0.40	0.30	0.50	0.69	0.53
MS21044N5	C	5	400 in.-lbs.	0.22	0.38	0.27	0.47	0.56	0.49
MS21044N6 (Green Insert)	C	5	500 in.-lbs.	0.28	0.43	0.33	0.10	0.11	0.11
MS21044N6 (Red Insert)	C	5	500 in.-lbs.	0.23	0.38	0.28	0.12 for one sample only*		
MS21044N8	C	5	125 ft.-lbs.	0.23	0.33	0.28	0.23	0.33	0.30
Average				0.24	0.44	0.30	0.31	0.47	0.47

*No data on four samples threads stripped.

TABLE VIII. FRICTION FACTOR FOR MS21045 NUTS

Part Number and Size	Sample Type, See Figures 1, 2, 3 or 4	Number of Samples Tested	Torque at which Friction Factor was Determined	Friction Factor Spread (First Cycle)		Five Samples Average Friction Factor (First Cycle)	Friction Factor Spread (Fifth Cycle)		Five Samples Average Friction Factor (Fifth Cycle)
				Low	High		Low	High	
MS21045L3	E	5	100 in.-lbs.	0.24	0.31	0.27	0.31	0.34	0.33
MS21045-3	E	5	100 in.-lbs.	0.19	0.29	0.22	0.38	0.53	0.44
MS21045L4	G	5	250 in.-lbs.	0.28	0.36	0.30	0.42	0.57	0.47
MS21045-4	E	5	250 in.-lbs.	0.17	0.23	0.20	0.36	0.42	0.40
MS21045L5	F	5	400 in.-lbs.	0.14	0.17	0.15	0.15*	0.16*	0.15*
MS21045-5	G	5	400 in.-lbs.	0.13	0.20	0.14	0.18	0.47	0.26
MS21045L6	H	5	500 in.-lbs.	0.14	0.18	0.15	0.12	0.14	0.13
MS21045-6	E	5	500 in.-lbs.	0.18	0.23	0.20	0.11	0.28	0.18
MS21045L8	H	5	125 ft.-lbs.	0.12	0.16	0.13	0.15	0.18	0.16
MS21045-8	H	5	125 ft.-lbs.	0.15	0.18	0.16	0.16	0.26	0.19
Average (With and Without Dry Film Lub)				0.17	0.23	0.19	0.23	0.34	0.27
Average (Dry Film Lub only)				0.18	0.24	0.20	0.23	0.28	0.25
Average (Without Dry Film Lub only)				0.16	0.23	0.18	0.24	0.39	0.29

*No data on one sample threads stripped.

TABLE IX. FRICTION FACTOR FOR MS21245 NUTS

Part Number and Size	Sample Type, See Figures 1, 2, 3, or 4	Number of Samples Tested	Torque at which Friction Factor was Determined	Friction Factor Spread (First Cycle) Low	Friction Factor Spread (First Cycle) High	Five Samples Average Friction Factor (First Cycle)	Friction Factor Spread (Fifth Cycle) Low	Friction Factor Spread (Fifth Cycle) High	Five Samples Average Friction Factor (Fifth Cycle)
MS21245L8	K	5	75 ft.-lbs.	0.13	0.16	0.14	0.18	0.27	0.22
MS21245-8	K	5	75 ft.-lbs.	0.14	0.19	0.16	0.48	0.60	0.53
Average				0.14	0.18	0.15	0.33	0.44	0.38

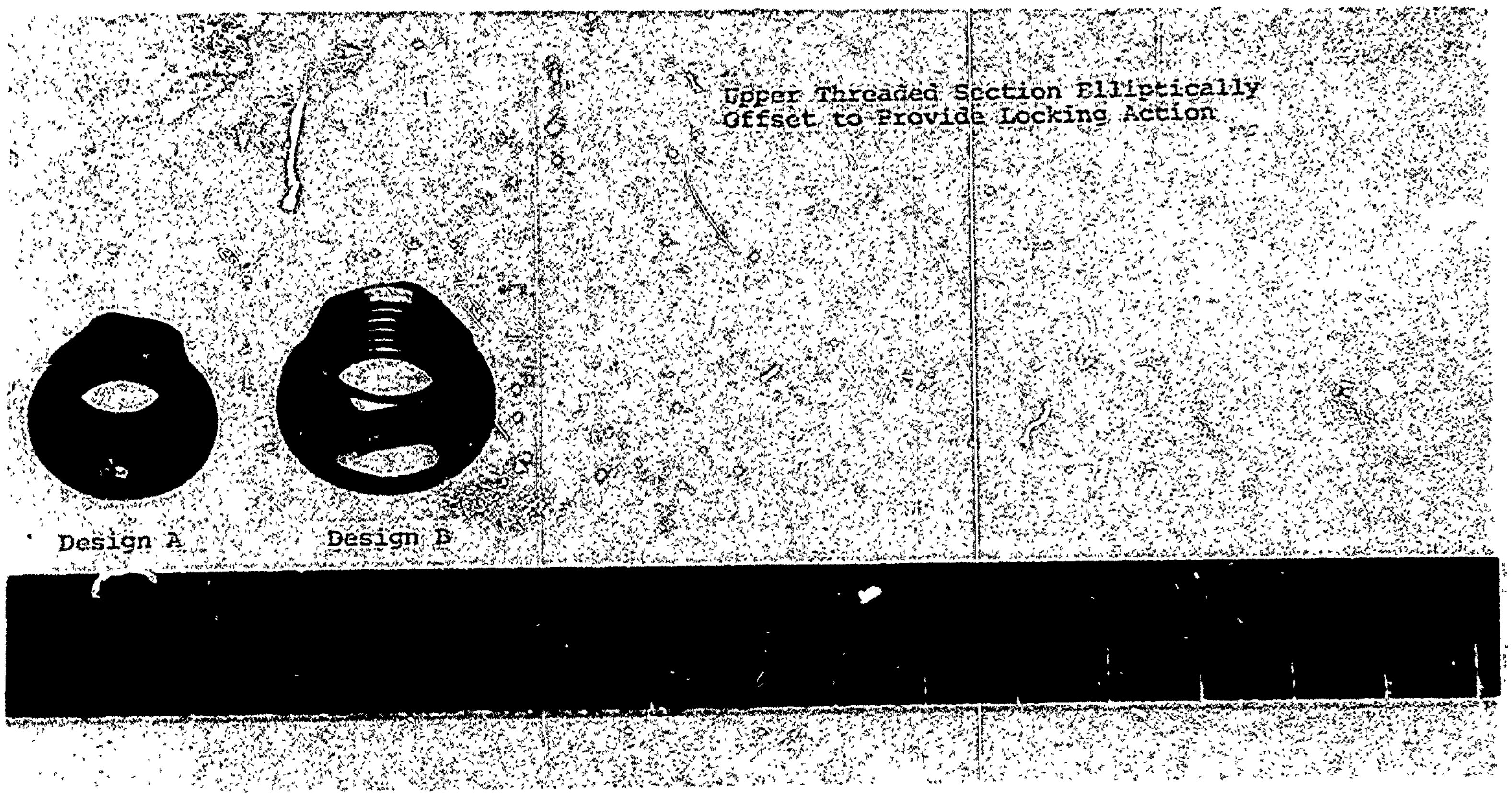

Figure 1. MS21042 Nut, Self-Locking, 450° F, Reduced Hexagon and Height

Figure 2. MS21044 Nut, Self-Locking, 250° F, Regular Hexagon and Height

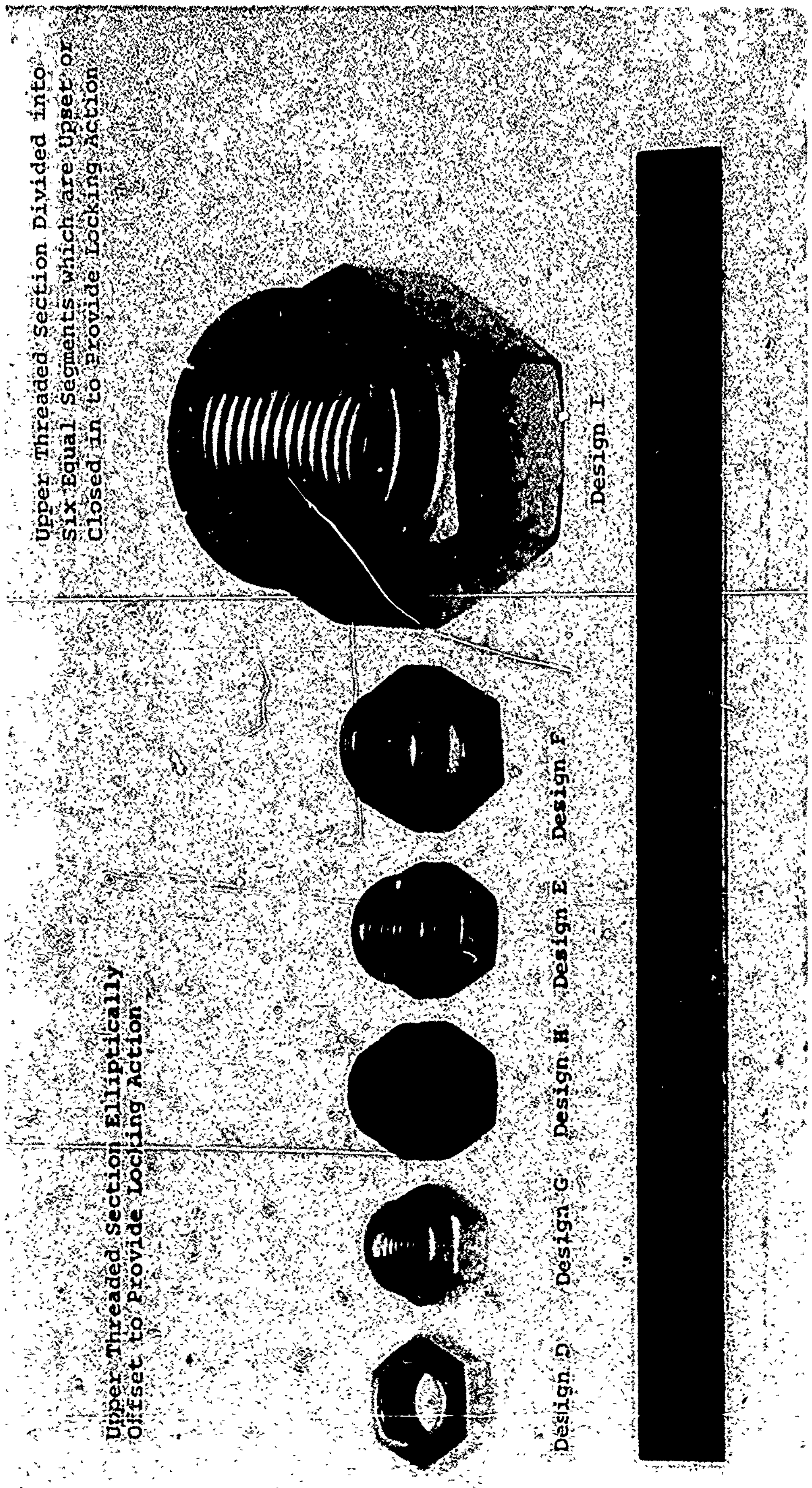

Figure 3. MS21045 Nut, Self-Locking, 450^{o} F, Regular Hexagon and Height

Figure 4. MS21245 Nut, Self-Locking, 450° F, Regular Hexagon, Reduced Height

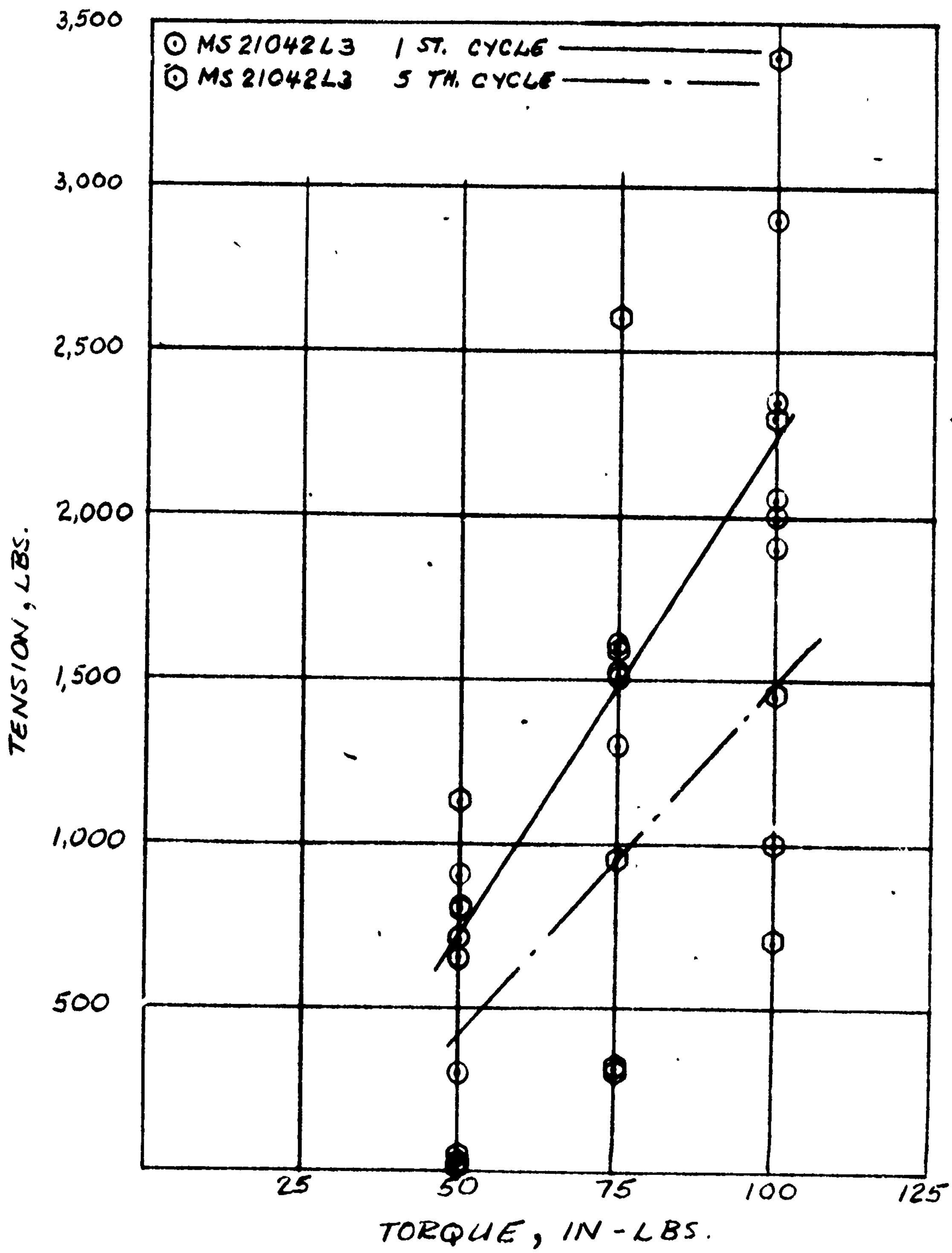

FIGURE 5. TORQUE - TENSION RELATIONSHIP FOR MS 21042L3

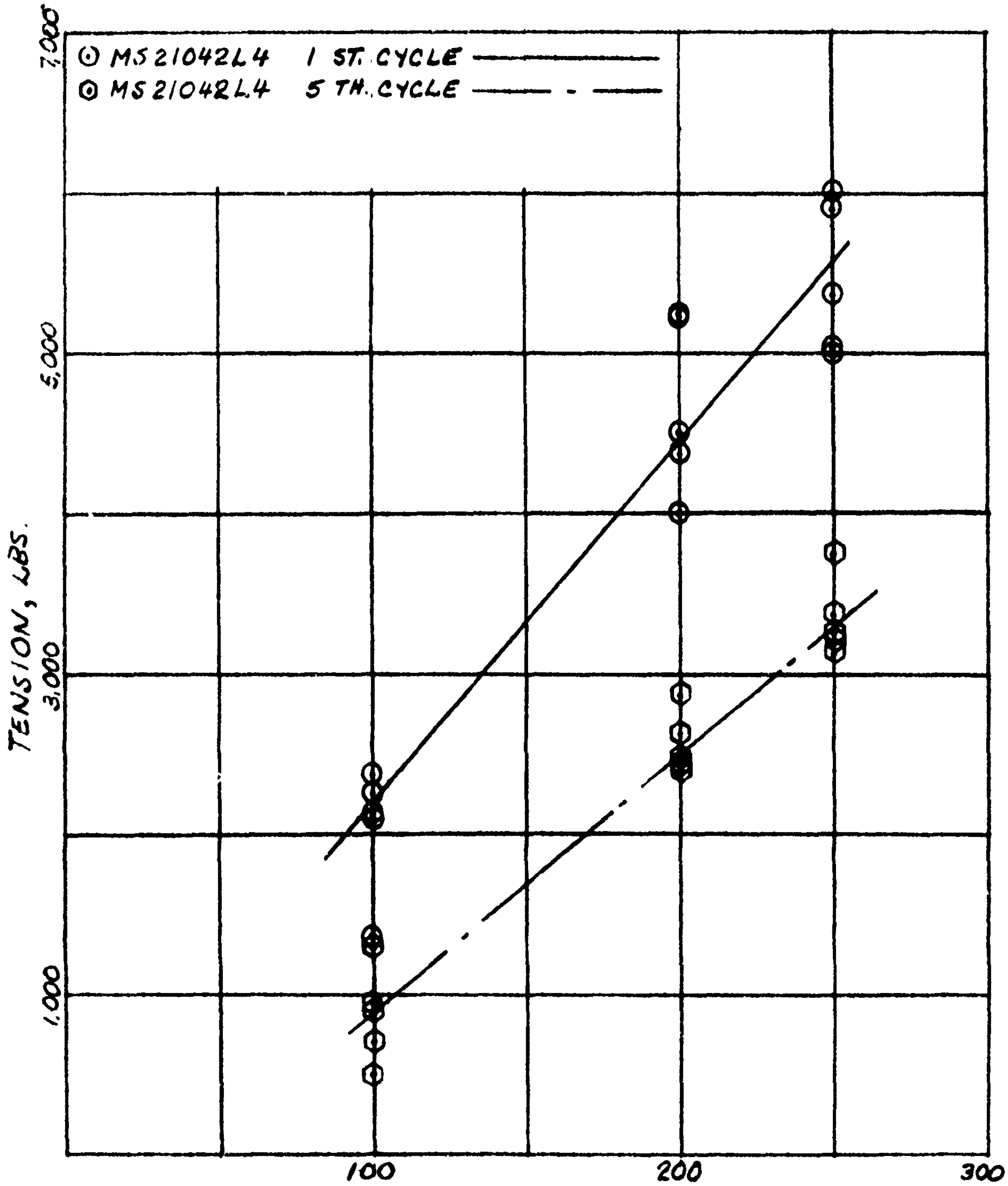

FIGURE 6. TORQUE-TENSION RELATIONSHIP FOR MS21042L4

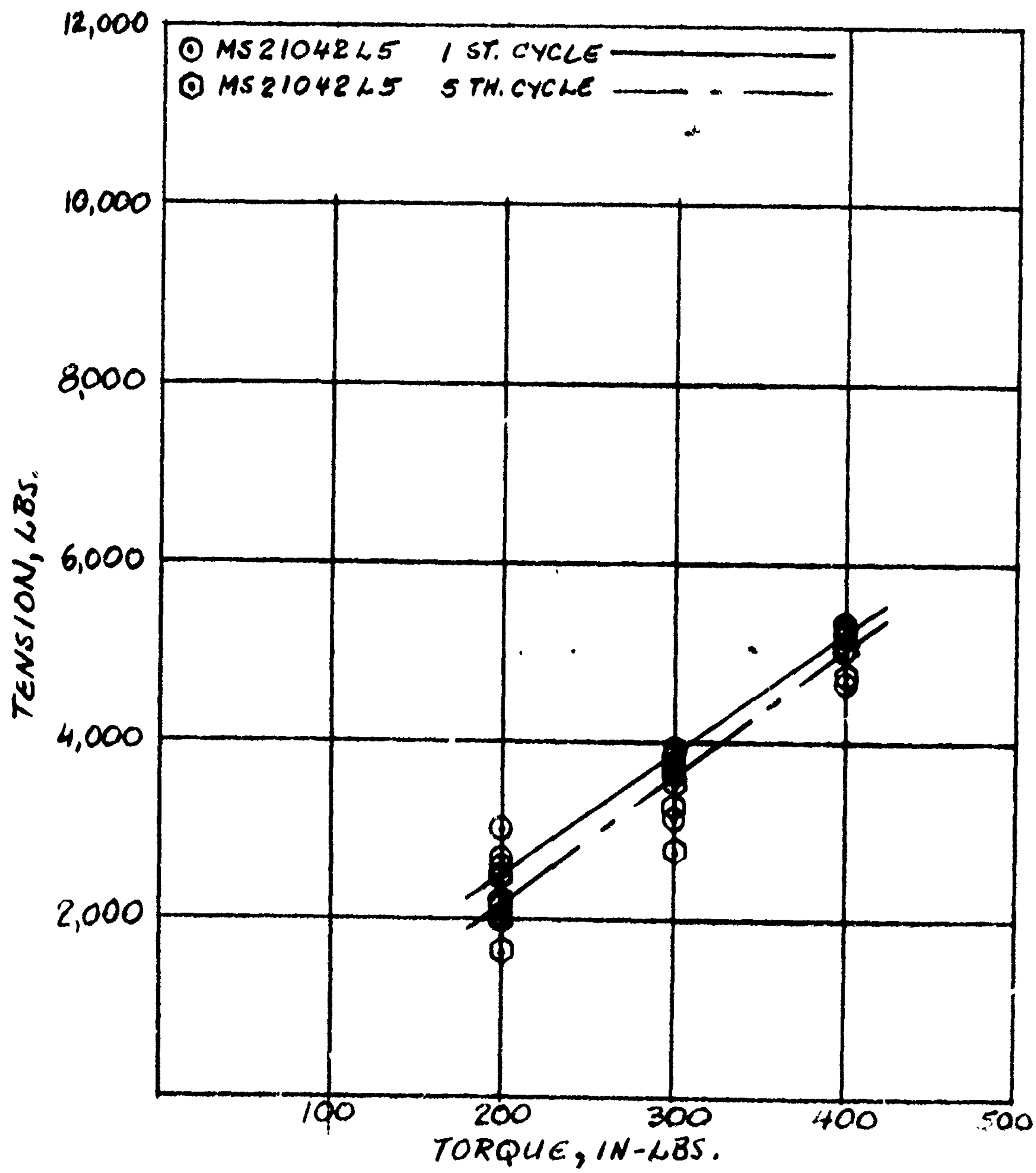

FIGURE 7. TORQUE-TENSION RELATIONSHIP FOR MS21042L5

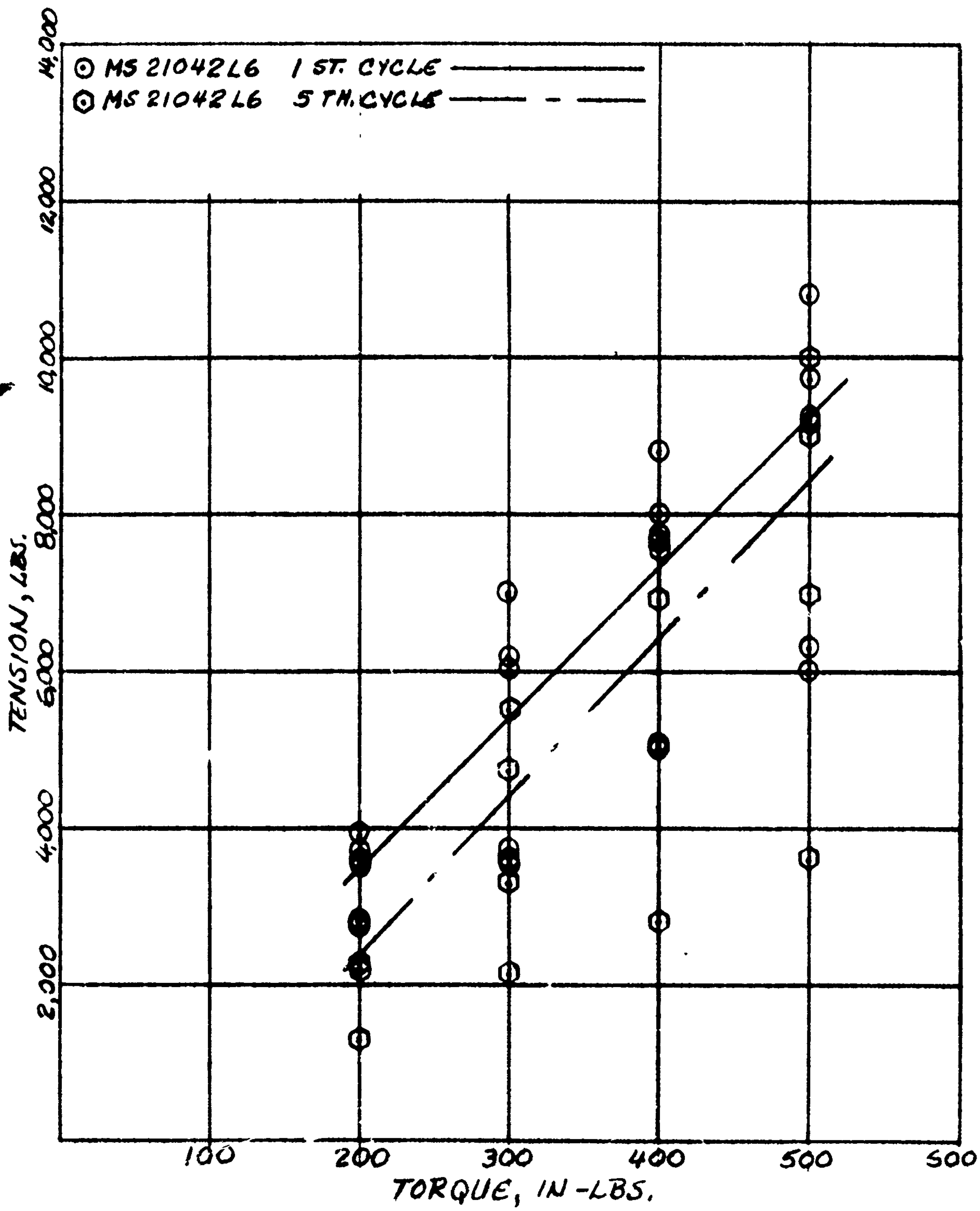

FIGURE 8. TORQUE-TENSION RELATIONSHIP FOR MS 21042L6

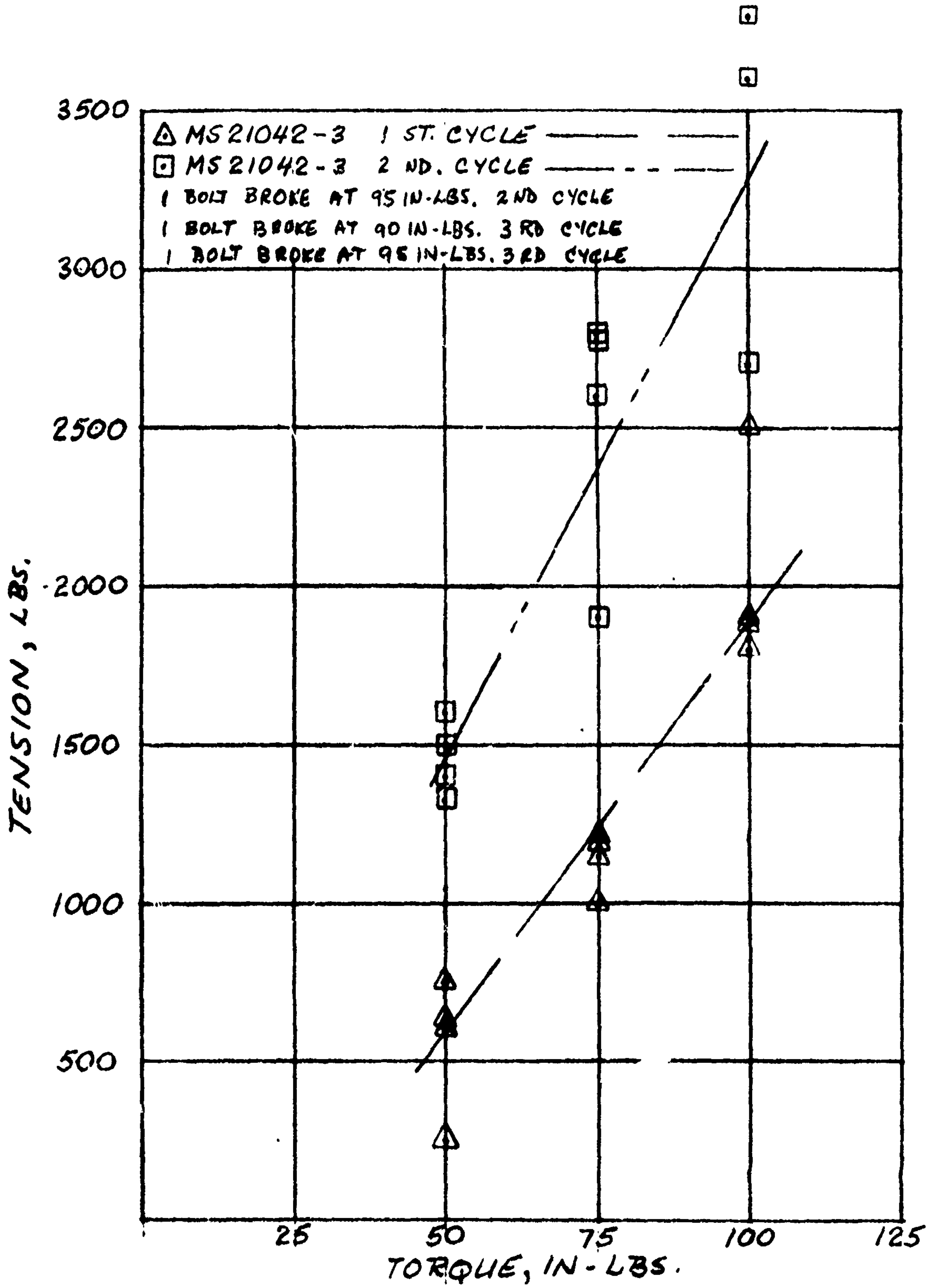

FIGURE 9. TORQUE-TENSION RELATIONSHIP FOR MS 21042-3

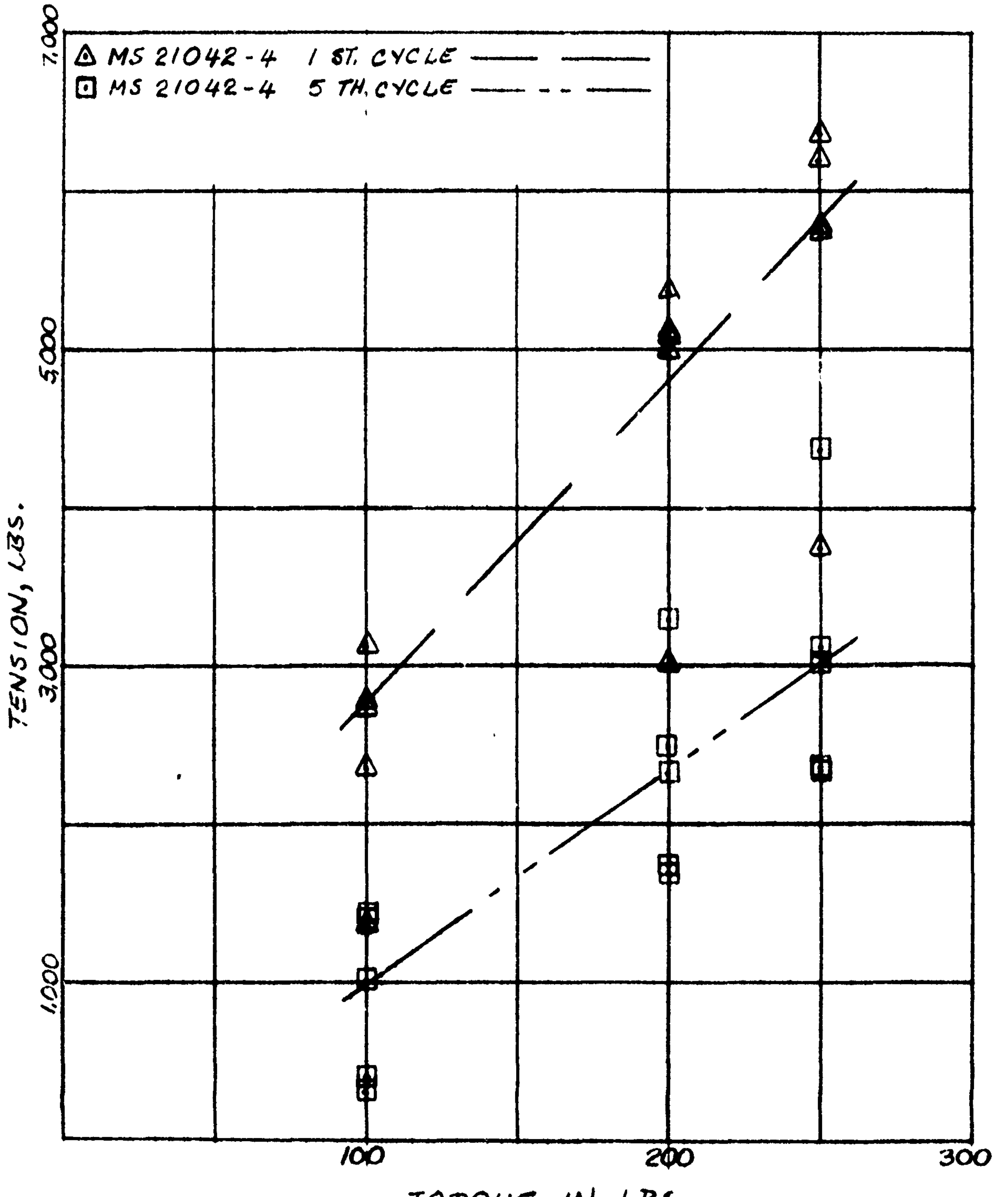

FIGURE 10. TORQUE-TENSION RELATIONSHIP FOR MS 21042-4

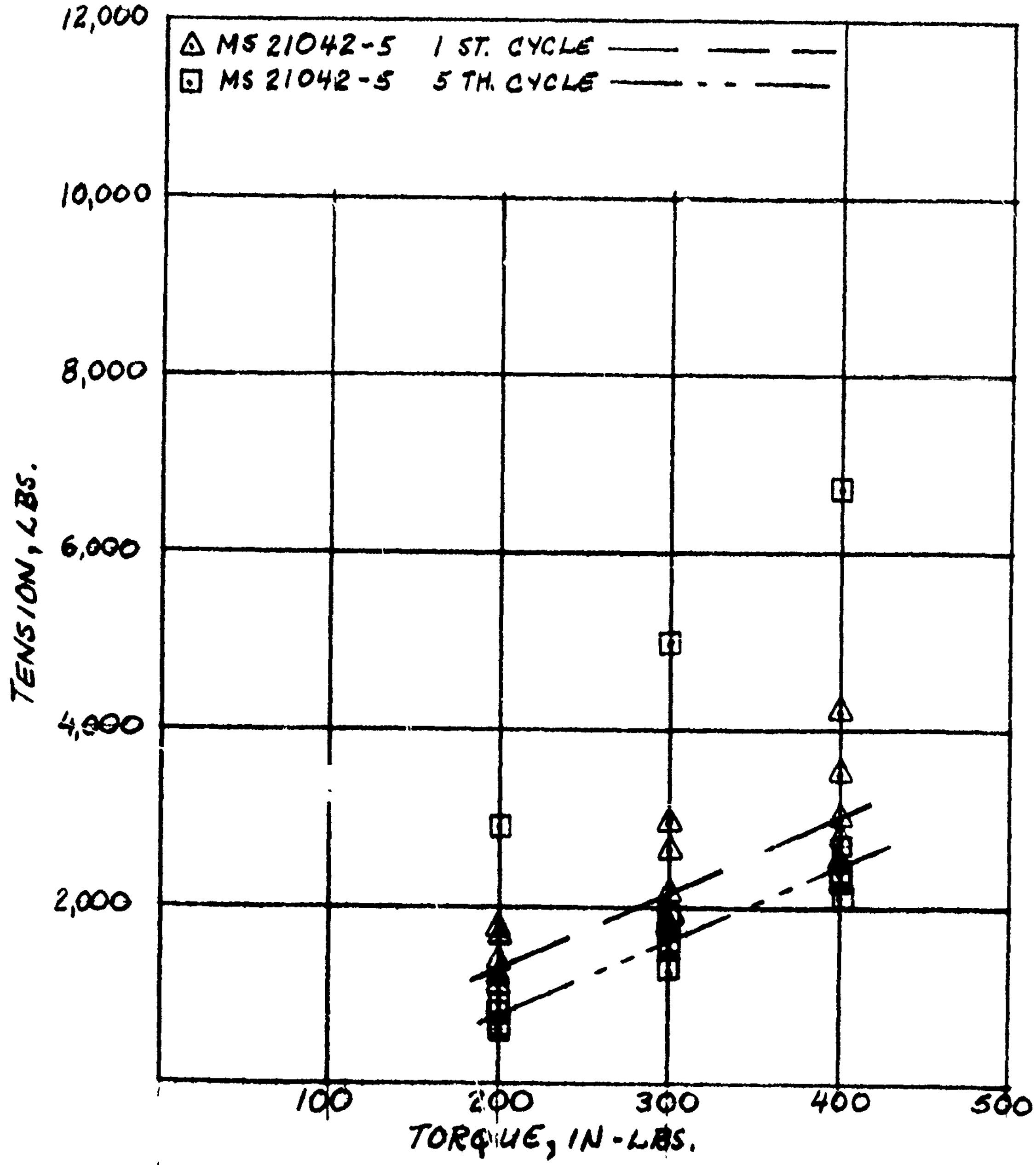

FIGURE 11. TORQUE-TENSION RELATIONSHIP FOR MS 21042-5

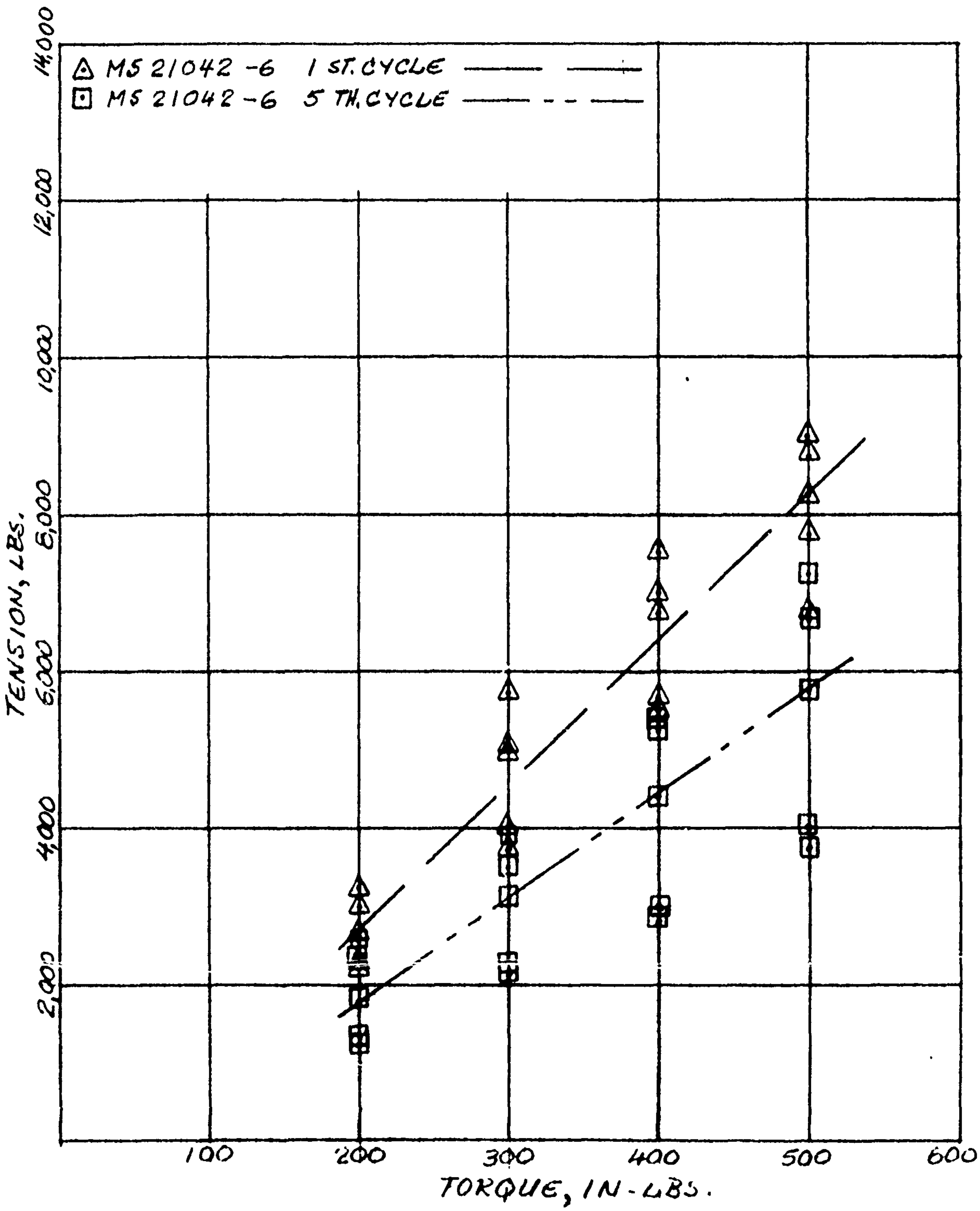

FIGURE 12. TORQUE-TENSION RELATIONSHIP FOR MS 21042-6

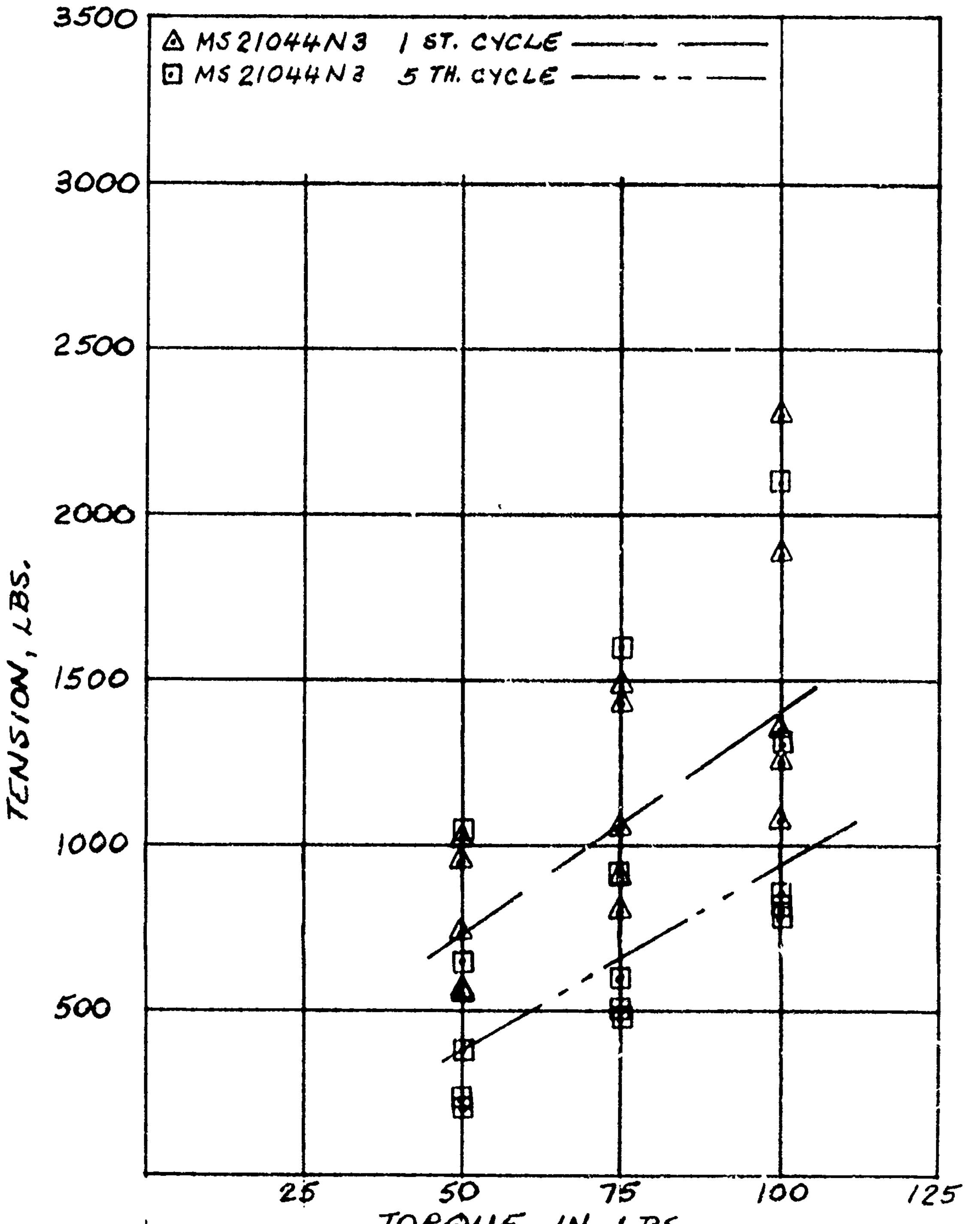

FIGURE 13. TORQUE–TENSION RELATIONSHIP FOR MS21044N3

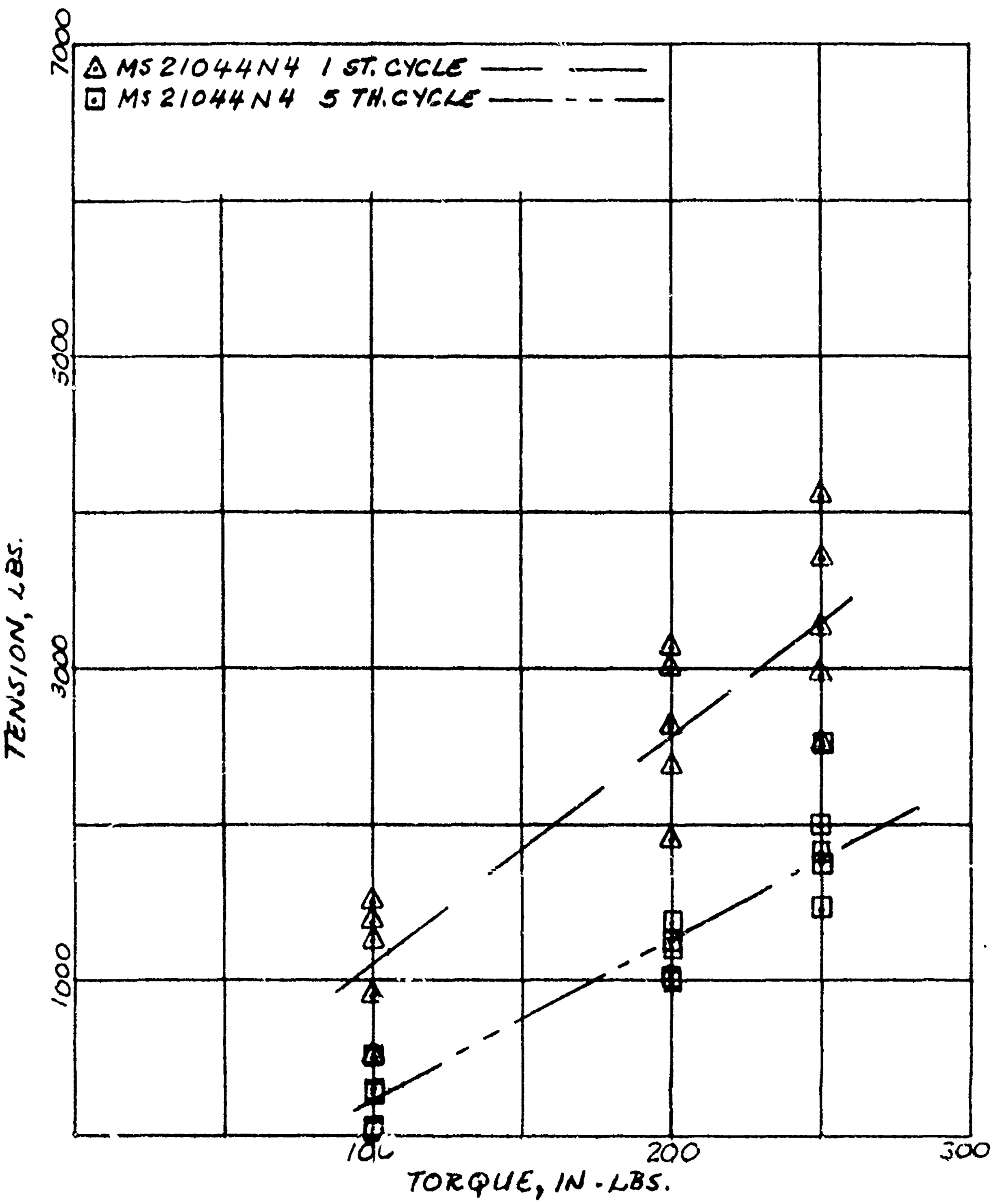

FIGURE 14. TORQUE-TENSION RELATIONSHIP FOR MS 21044N4

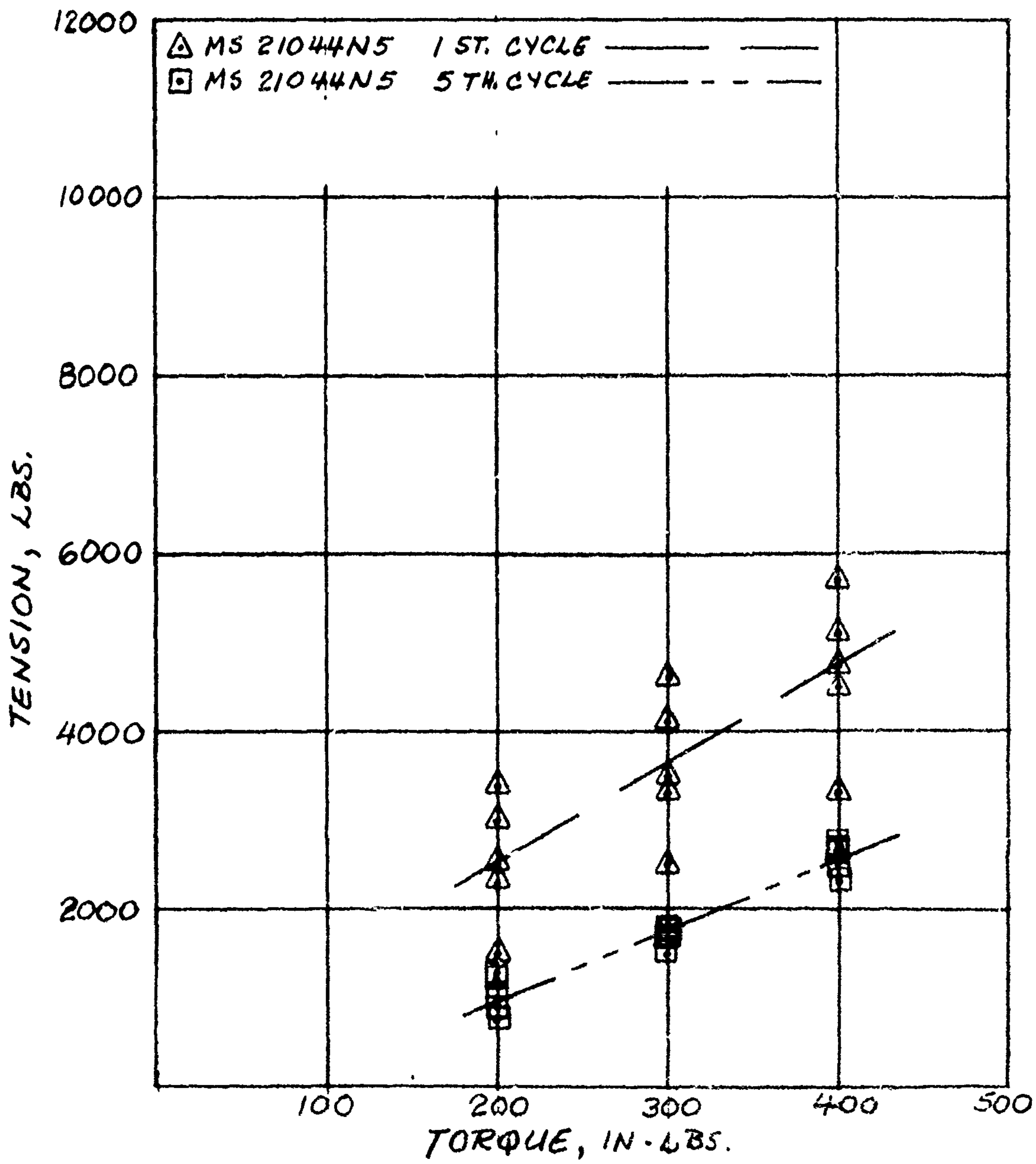

FIGURE 15. TORQUE-TENSION RELATIONSHIP FOR MS 21044N5

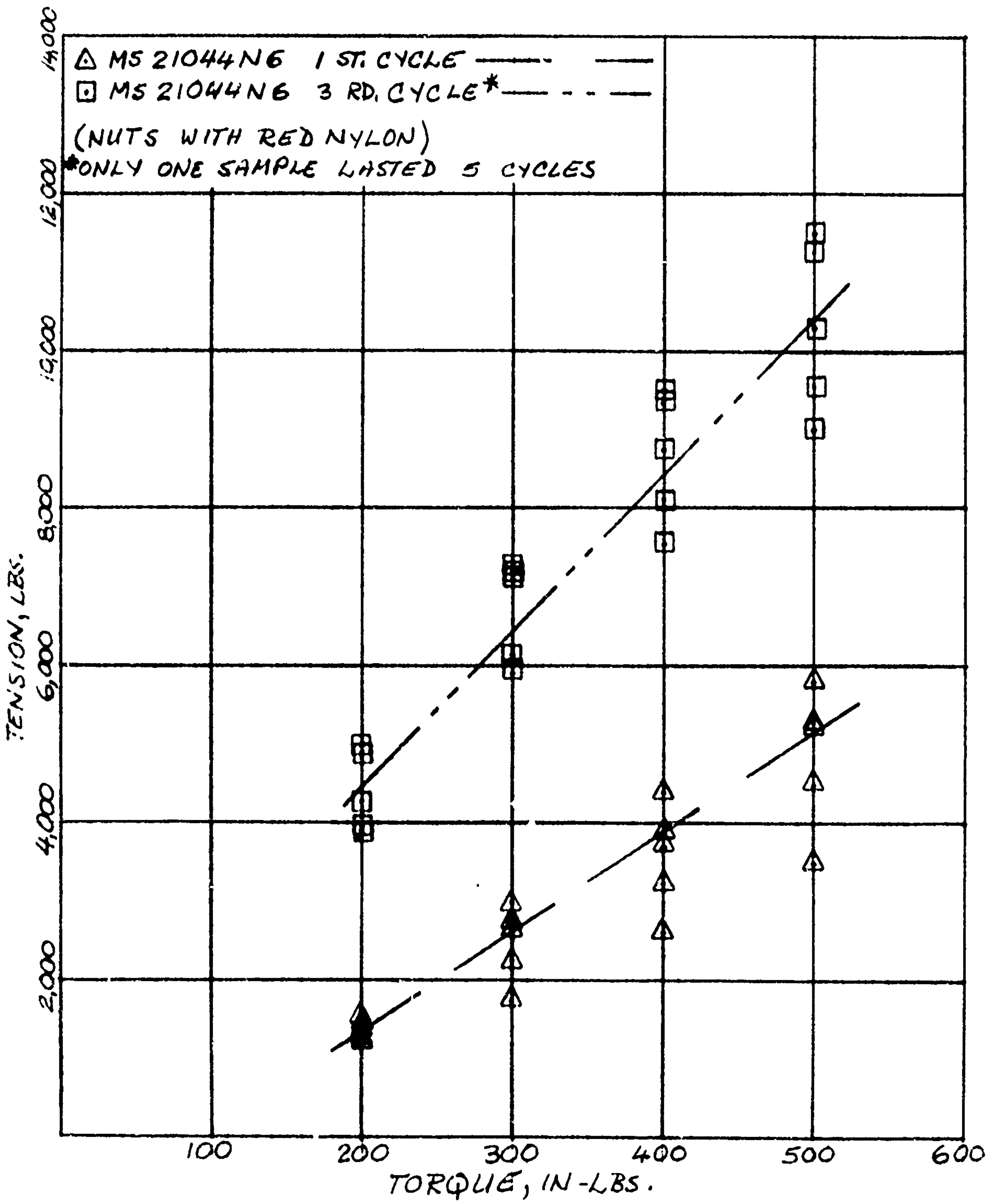

FIGURE 16. TORQUE–TENSION RELATIONSHIP FOR MS 21044N6 (RED NYLON)

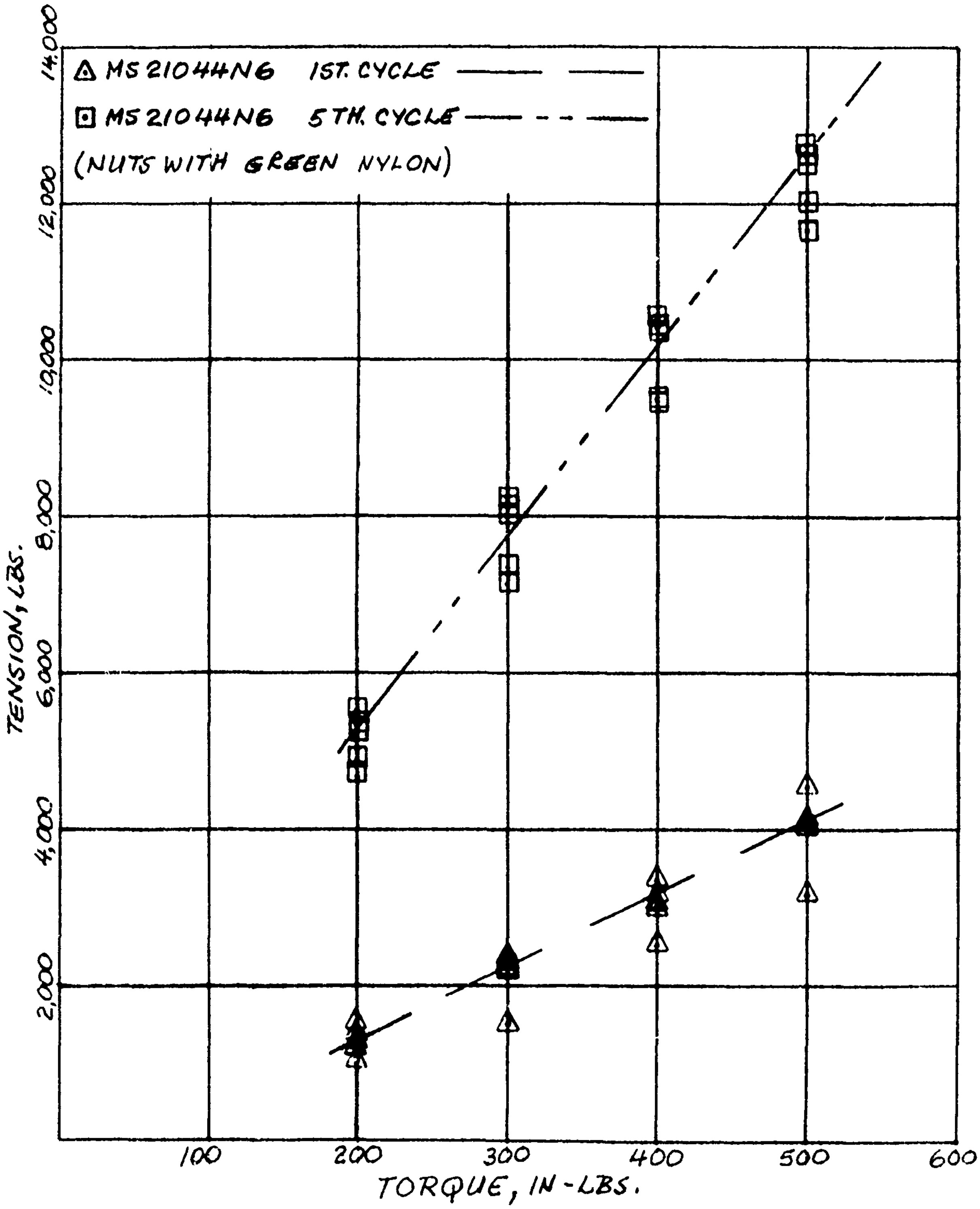

FIGURE 17. TORQUE-TENSION RELATIONSHIP FOR MS 21044N6 (GREEN NYLON)

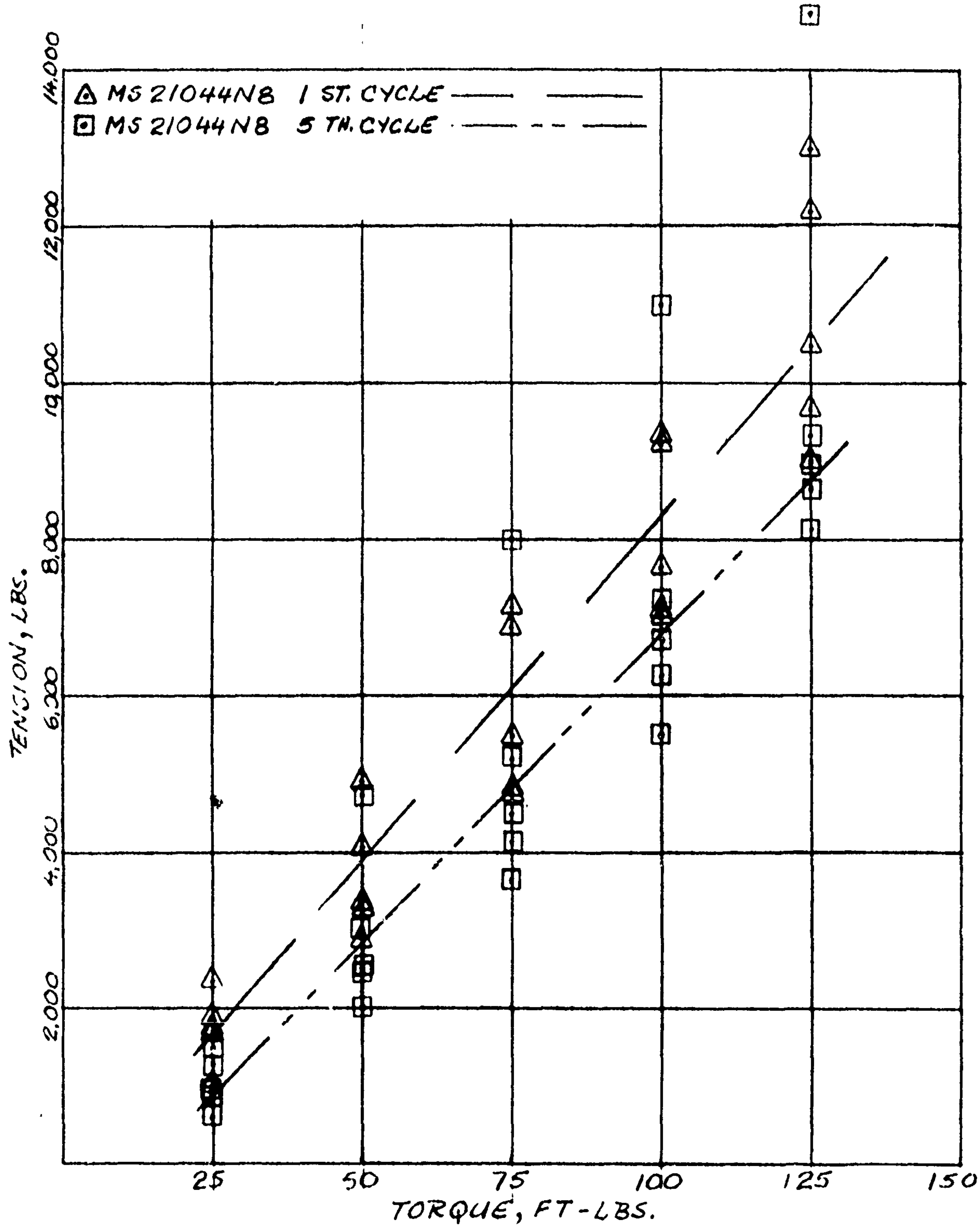

FIGURE 18. TORQUE-TENSION RELATIONSHIP FOR MS21044N8

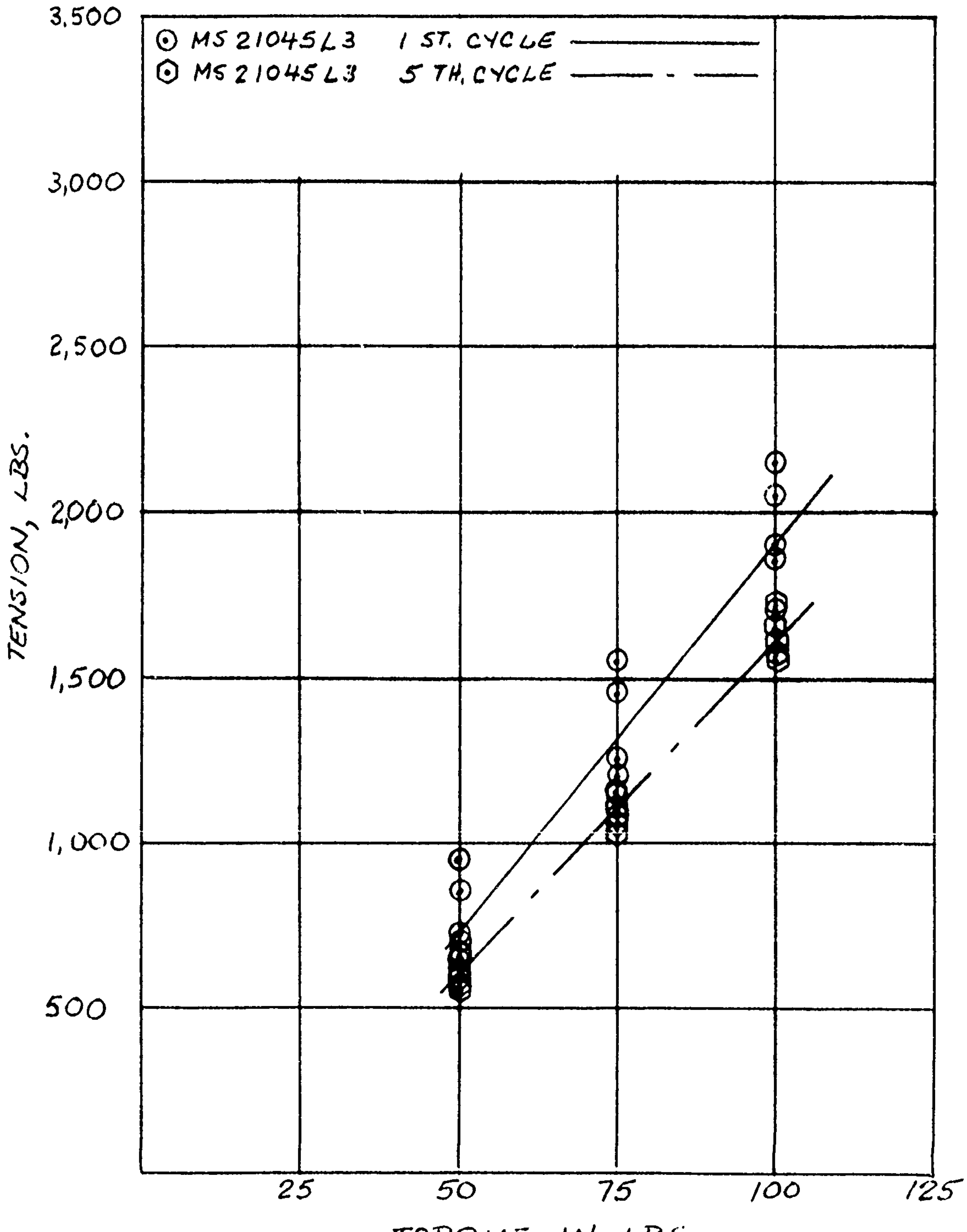

FIGURE 19. TORQUE-TENSION RELATIONSHIP FOR MS21045L3

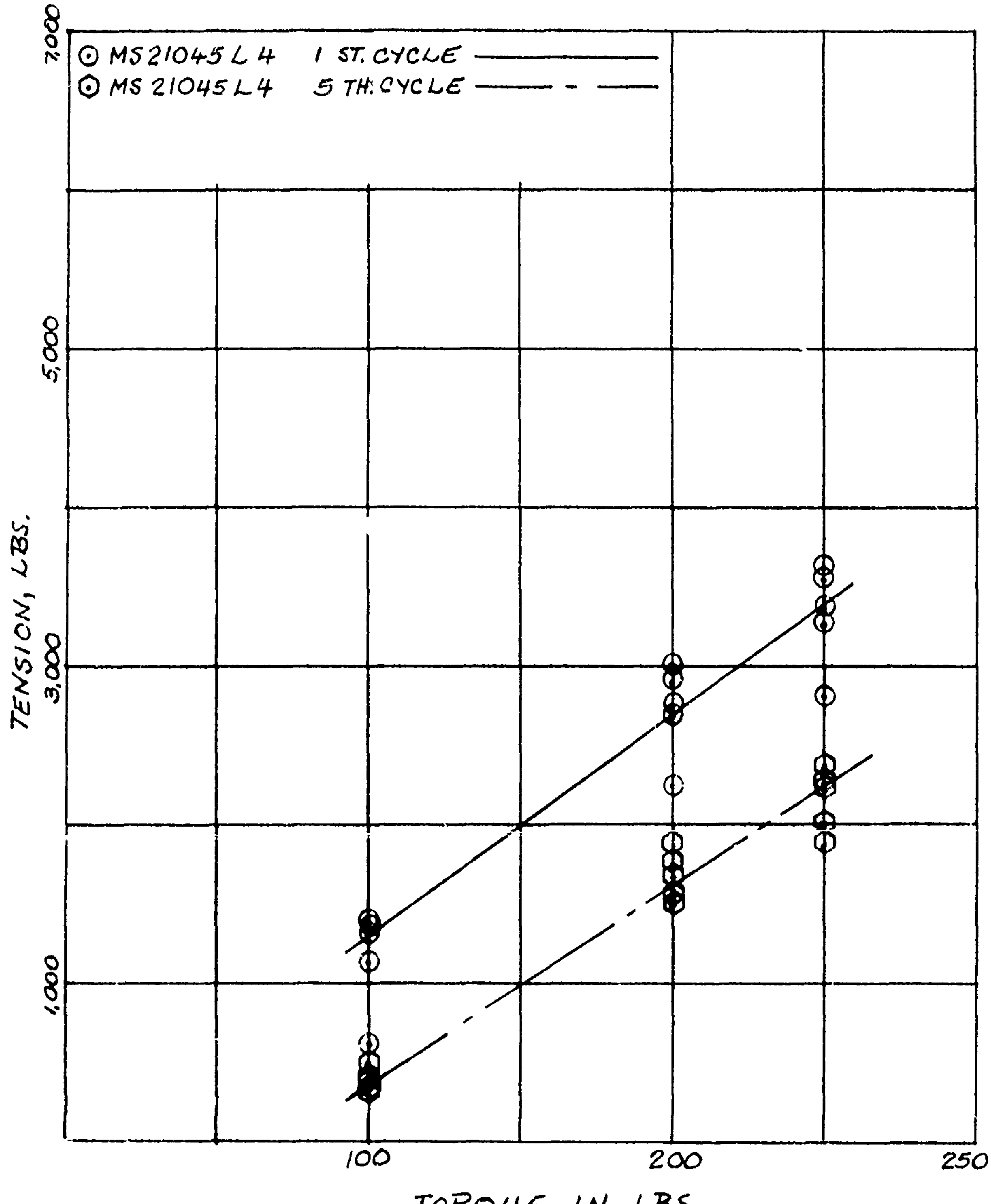

FIGURE 20. TORQUE-TENSION RELATIONSHIP FOR MS21045L4

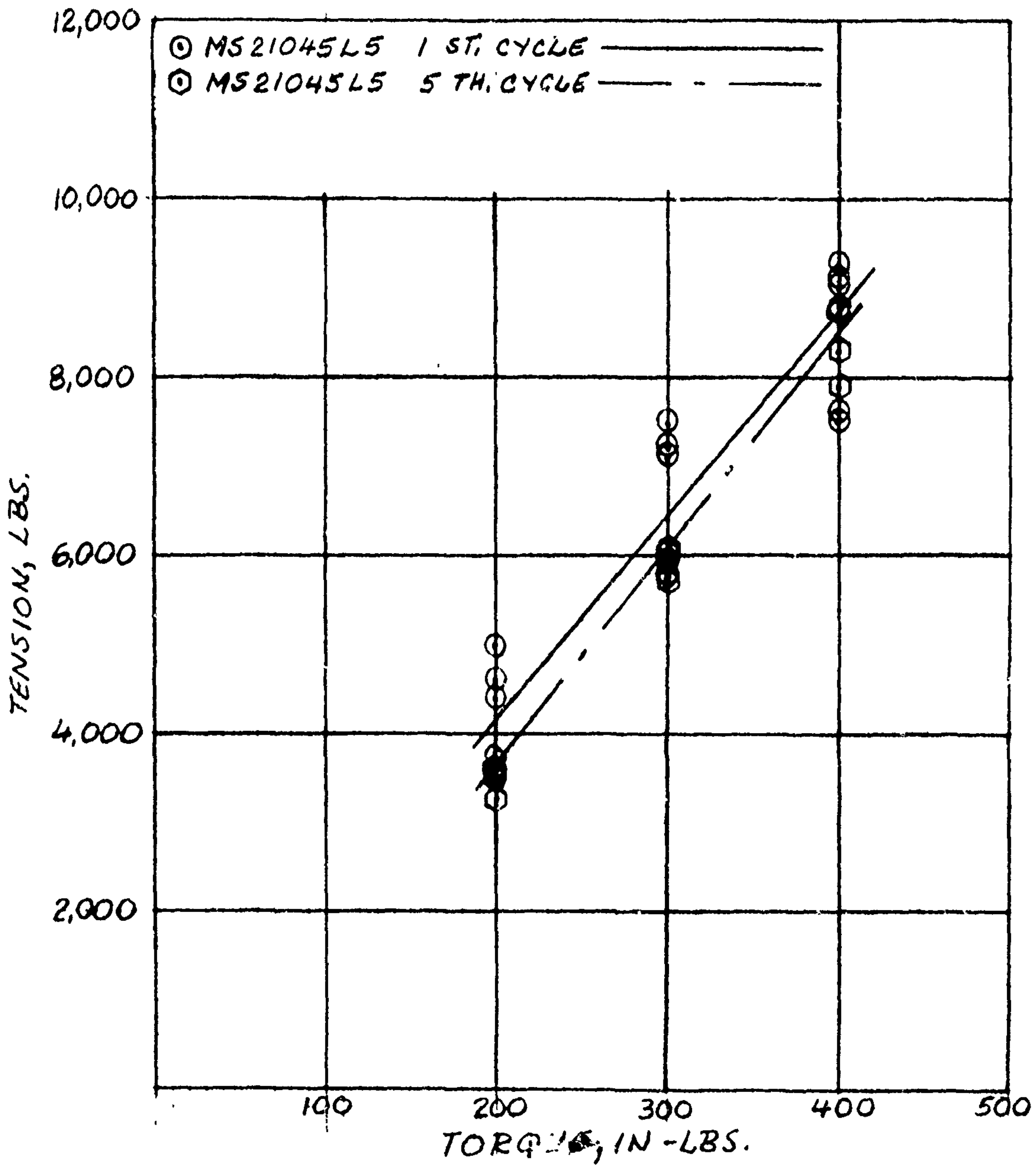

FIGURE 21. TORQUE-TENSION RELATIONSHIP FOR MS21045L5

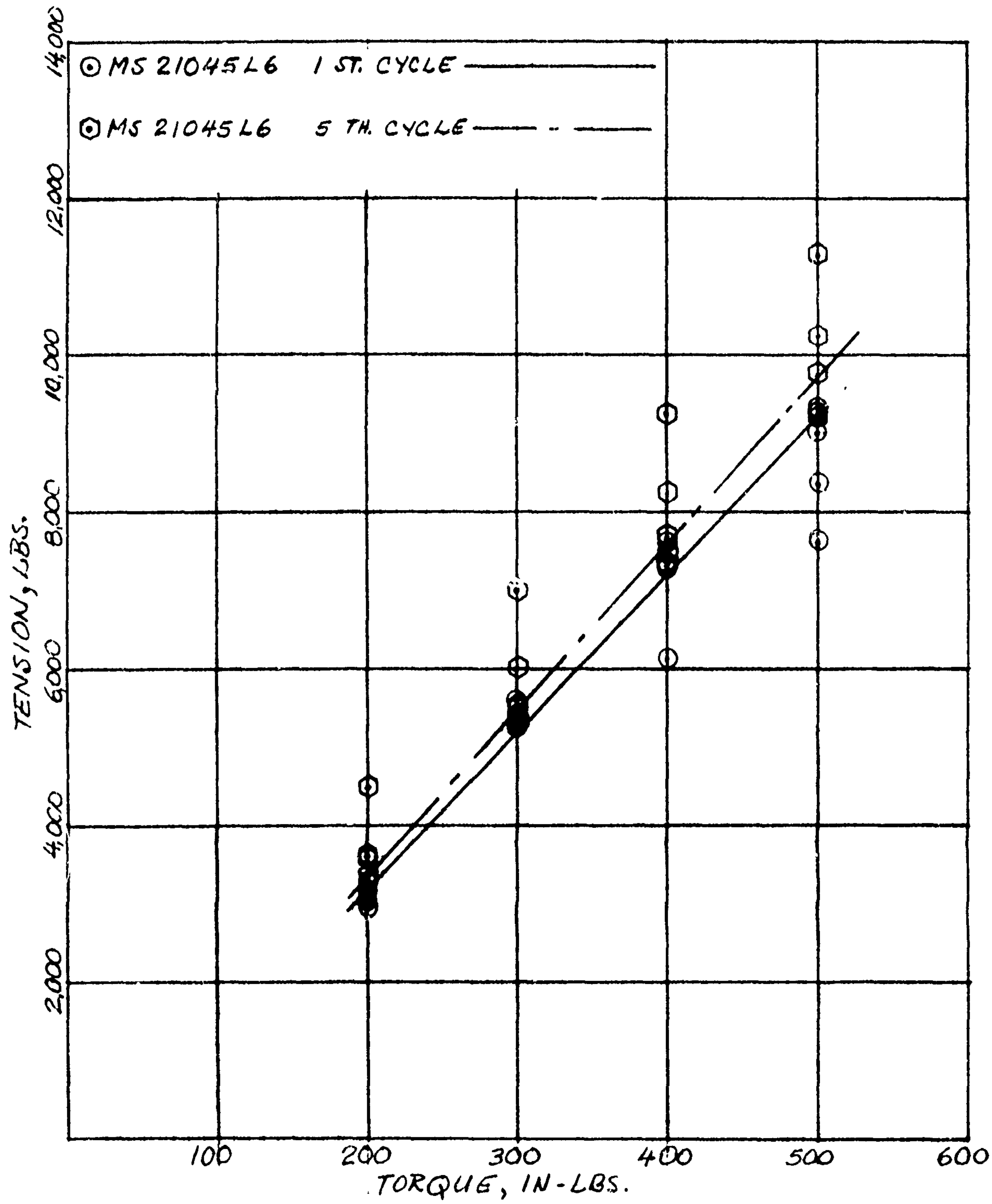

FIGURE 22. TORQUE-TENSION RELATIONSHIP FOR MS 21045L6

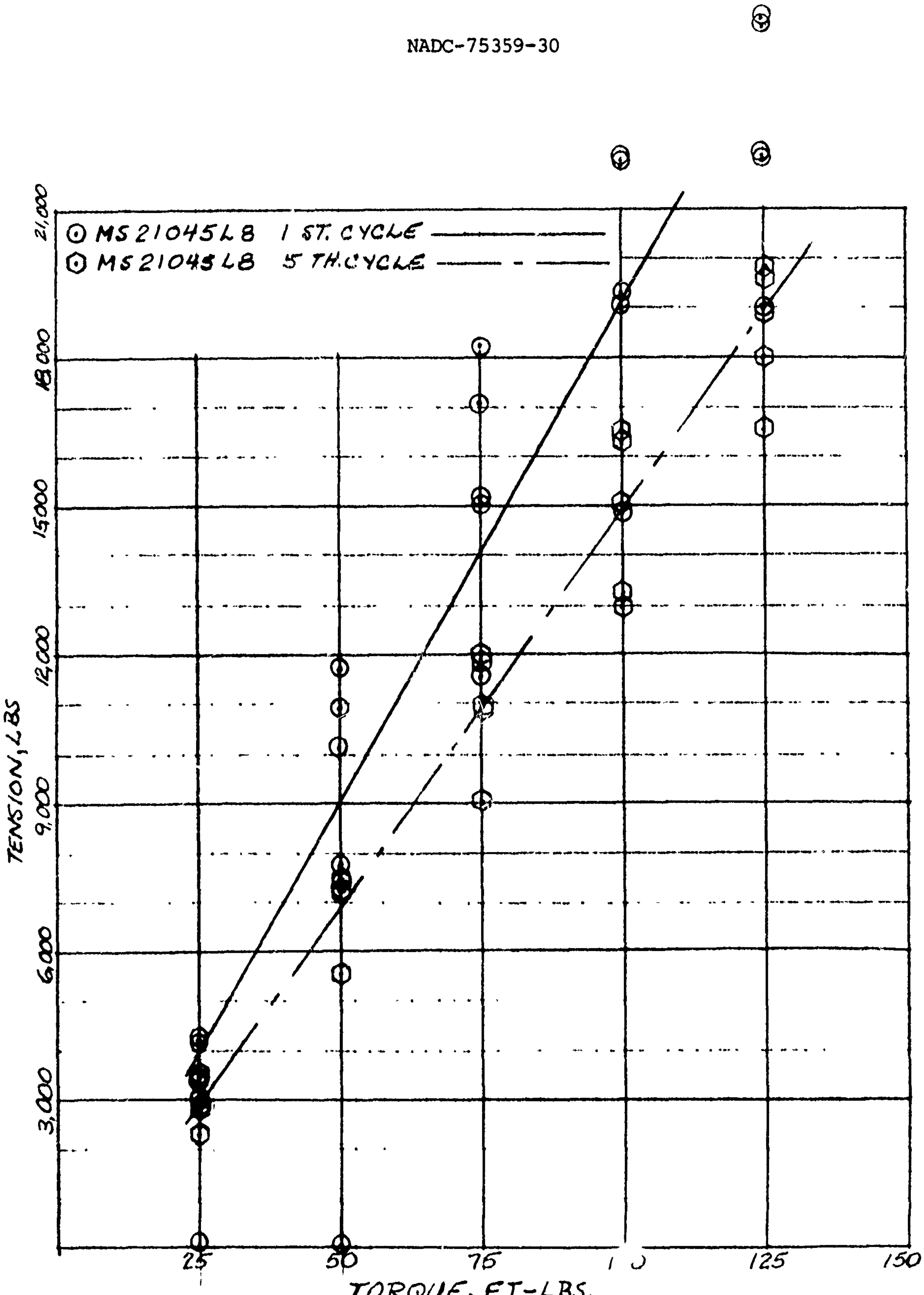

FIGURE 23. TORQUE-TENSION RELATIONSHIP FOR MS 21045L8

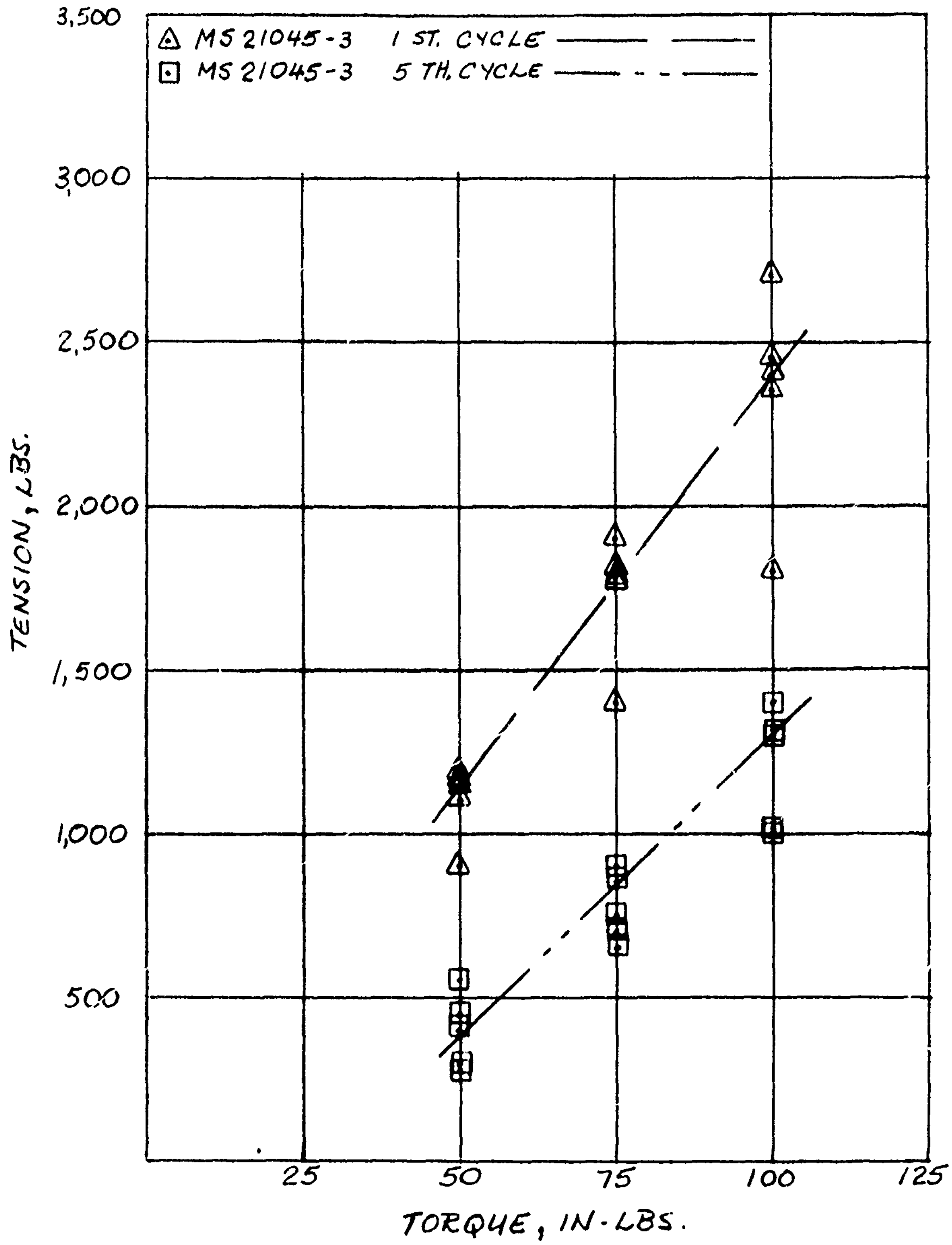

FIGURE 24. TORQUE-TENSION RELATIONSHIP FOR MS21045-3

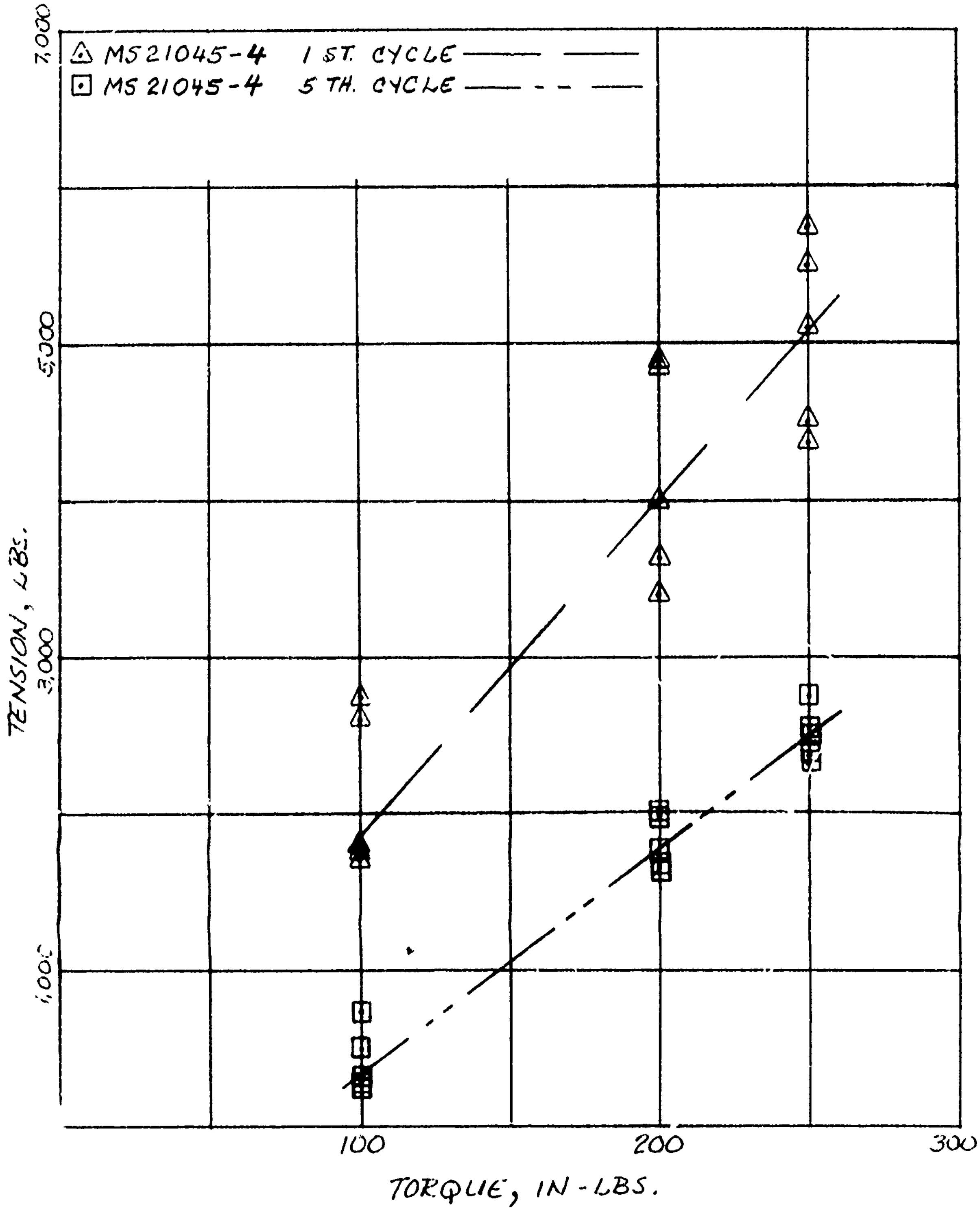

FIGURE 2.5. TORQUE-TENSION RELATIONSHIP FOR MS21045-4

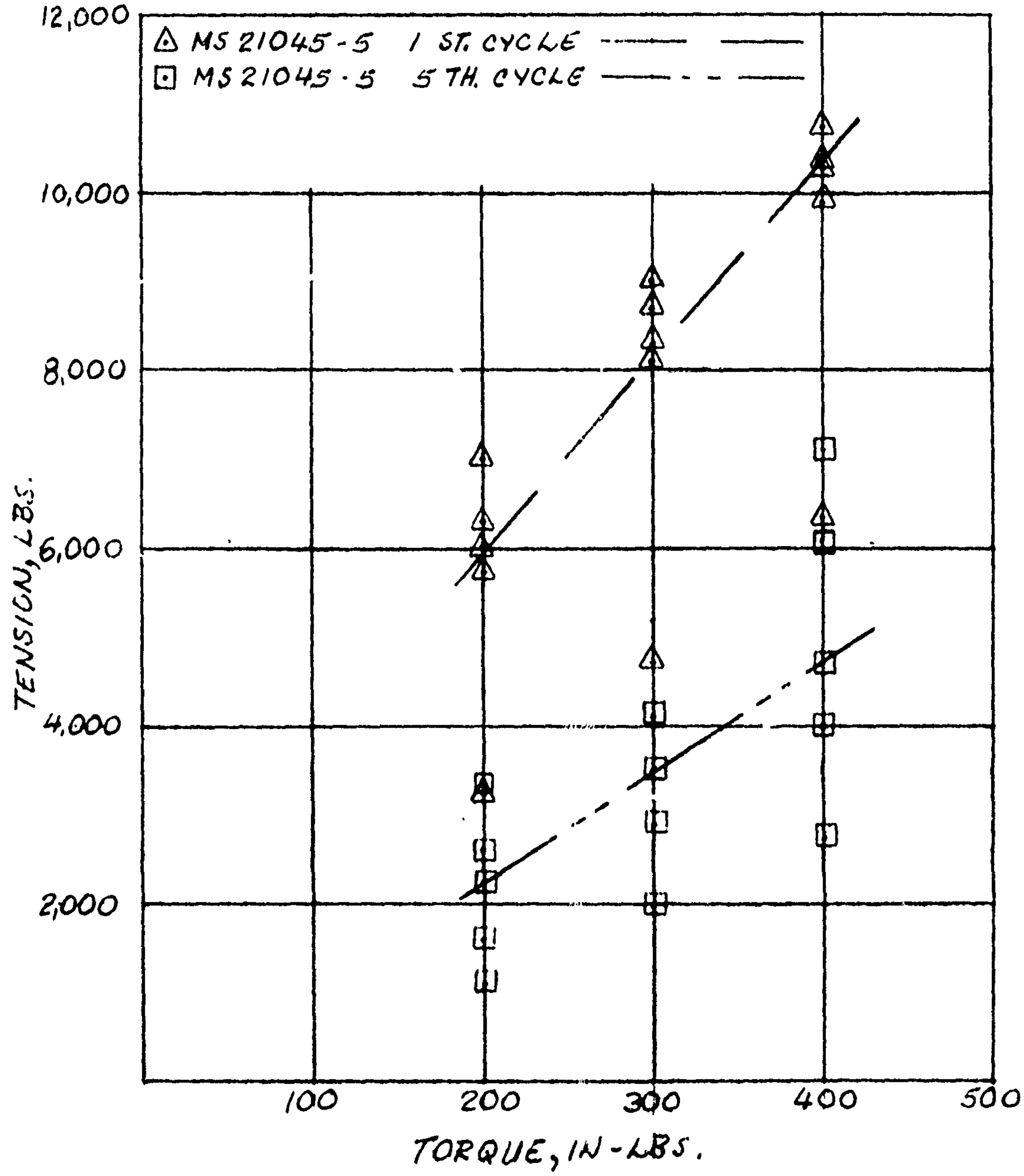

FIGURE 26. TORQUE-TENSION RELATIONSHIP FOR MS 21045-5

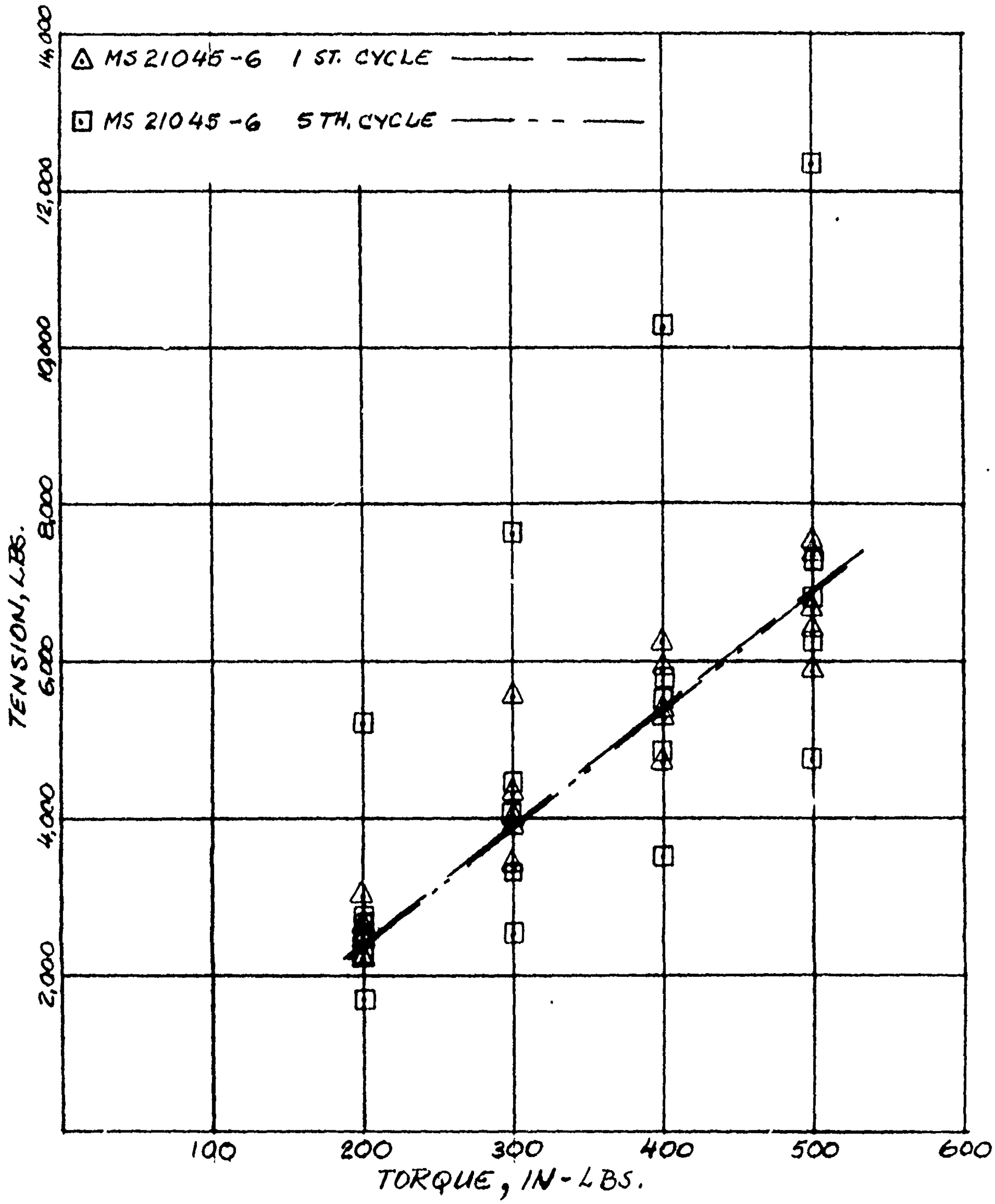

FIGURE 27. TORQUE-TENSION RELATIONSHIP FOR MS 21045-6

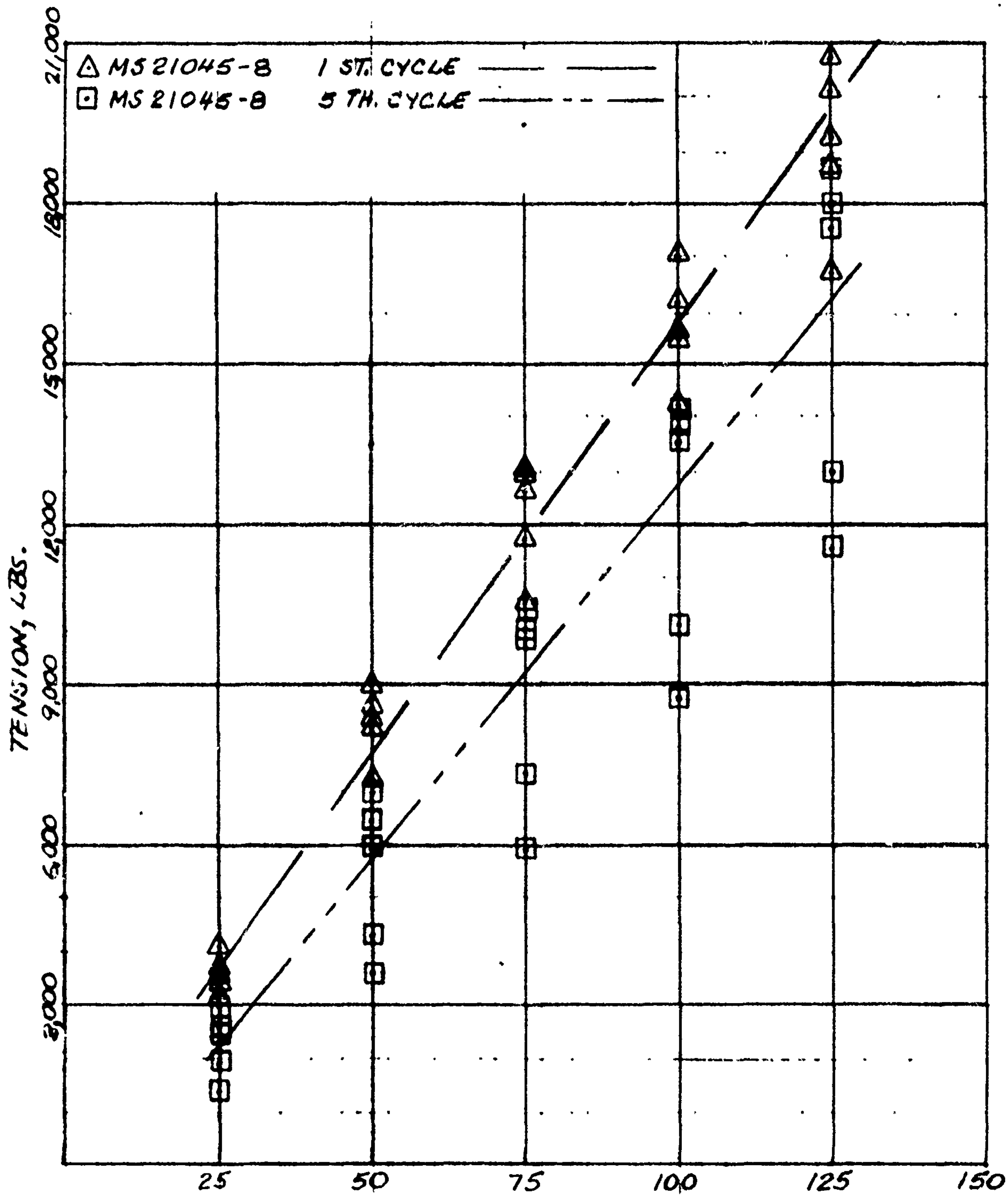

FIGURE 28. TORQUE-TENSION RELATIONSHIP FOR MS 21045-8

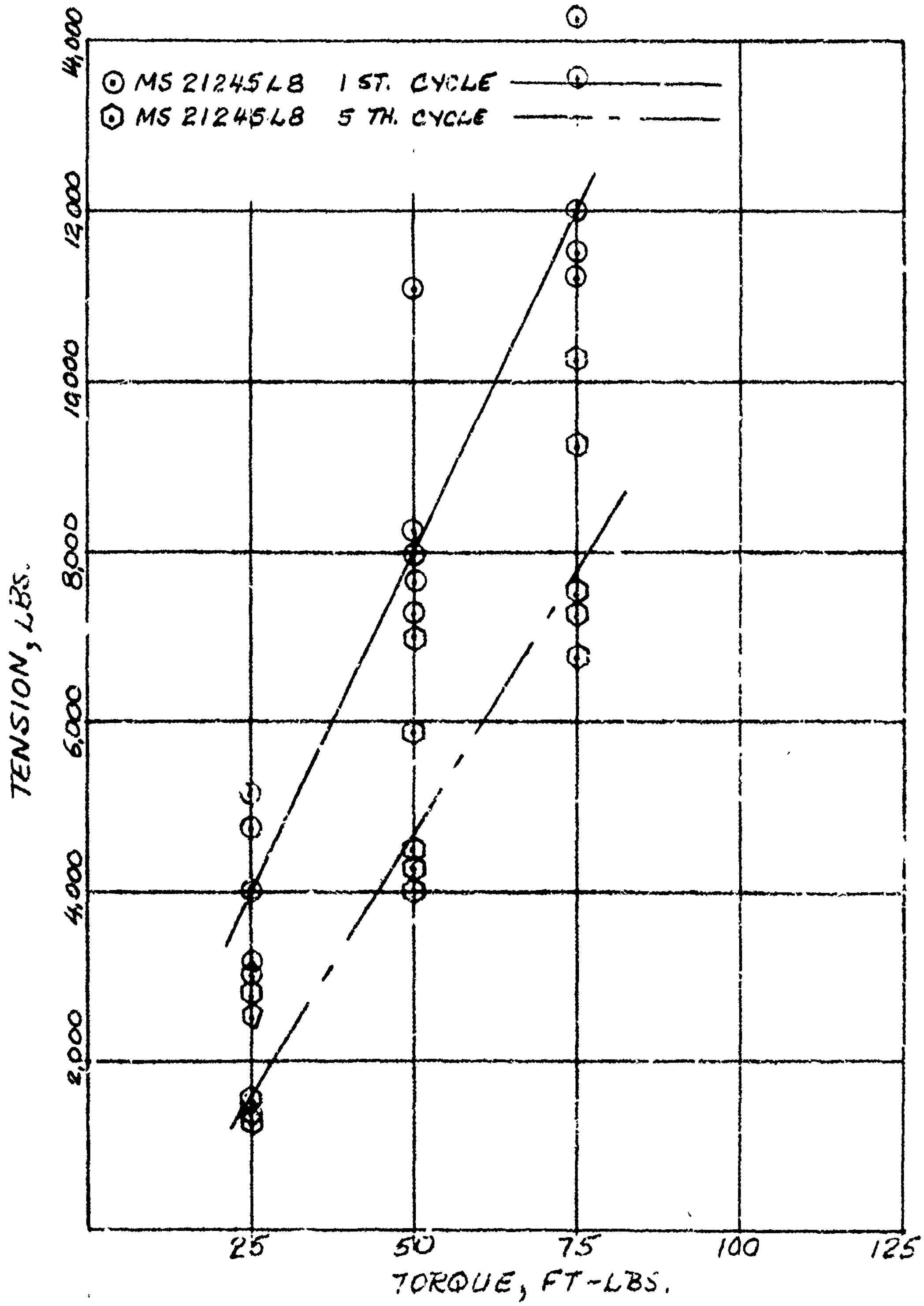

FIGURE 29. TORQUE-TENSION RELATIONSHIP FOR MS21245L8

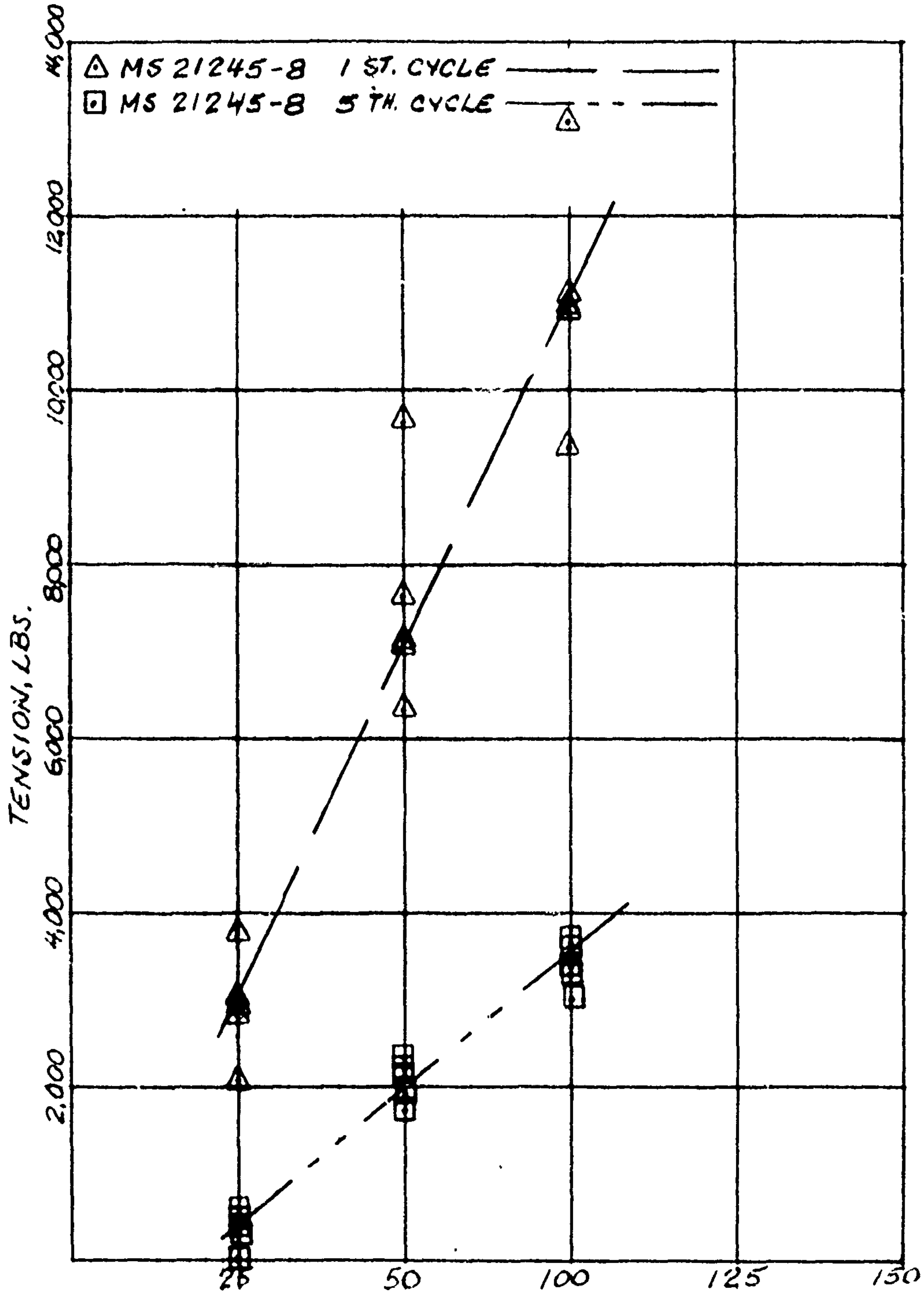

FIGURE 30. TORQUE-TENSION RELATIONSHIP FOR MS 21245-8

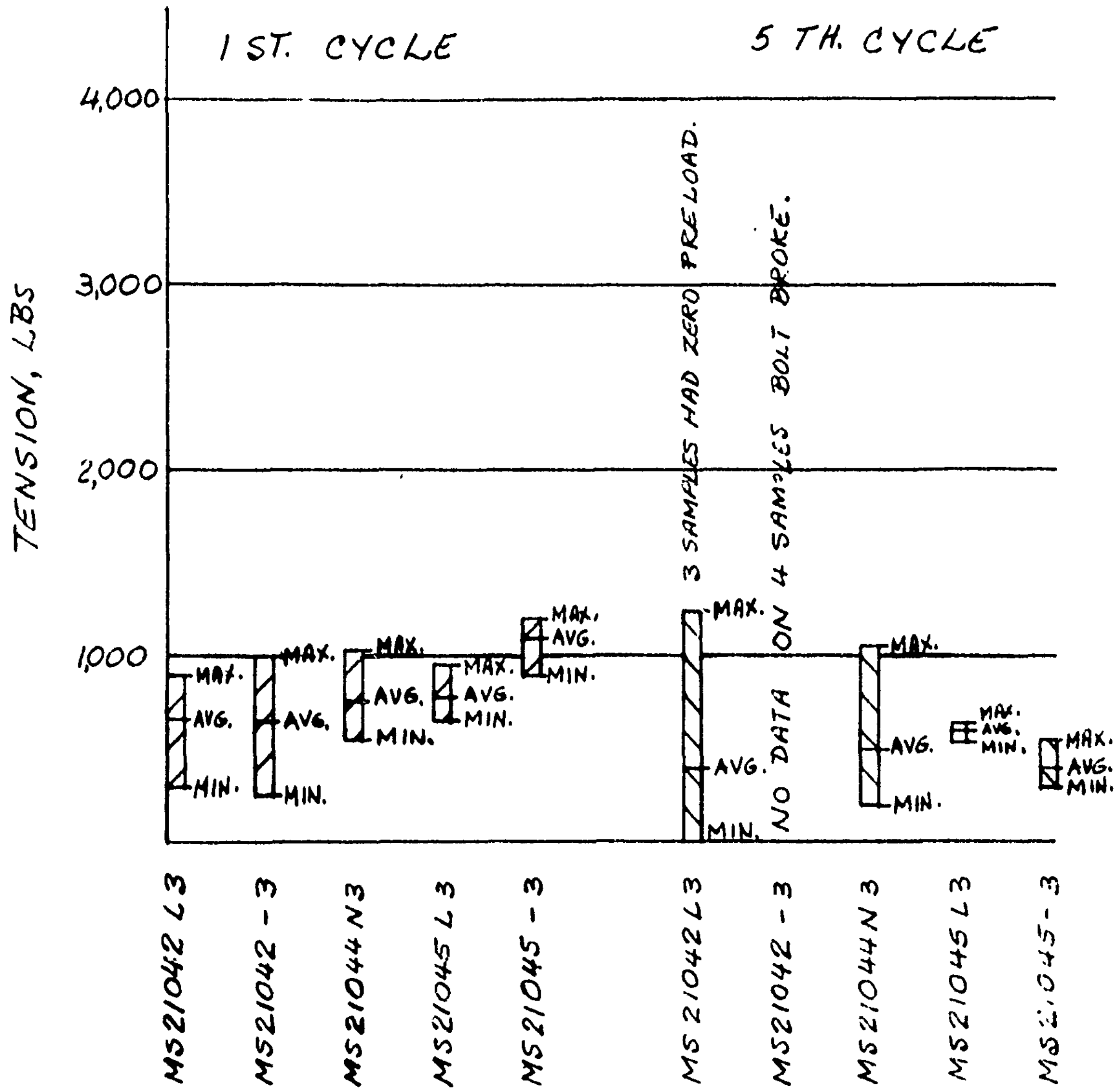

FIGURE 31. COMPARATIVE TORQUE - TENSION RELATIONSHIP FOR NO.10 SIZE NUTS TORQUED TO 50 IN-LBS.

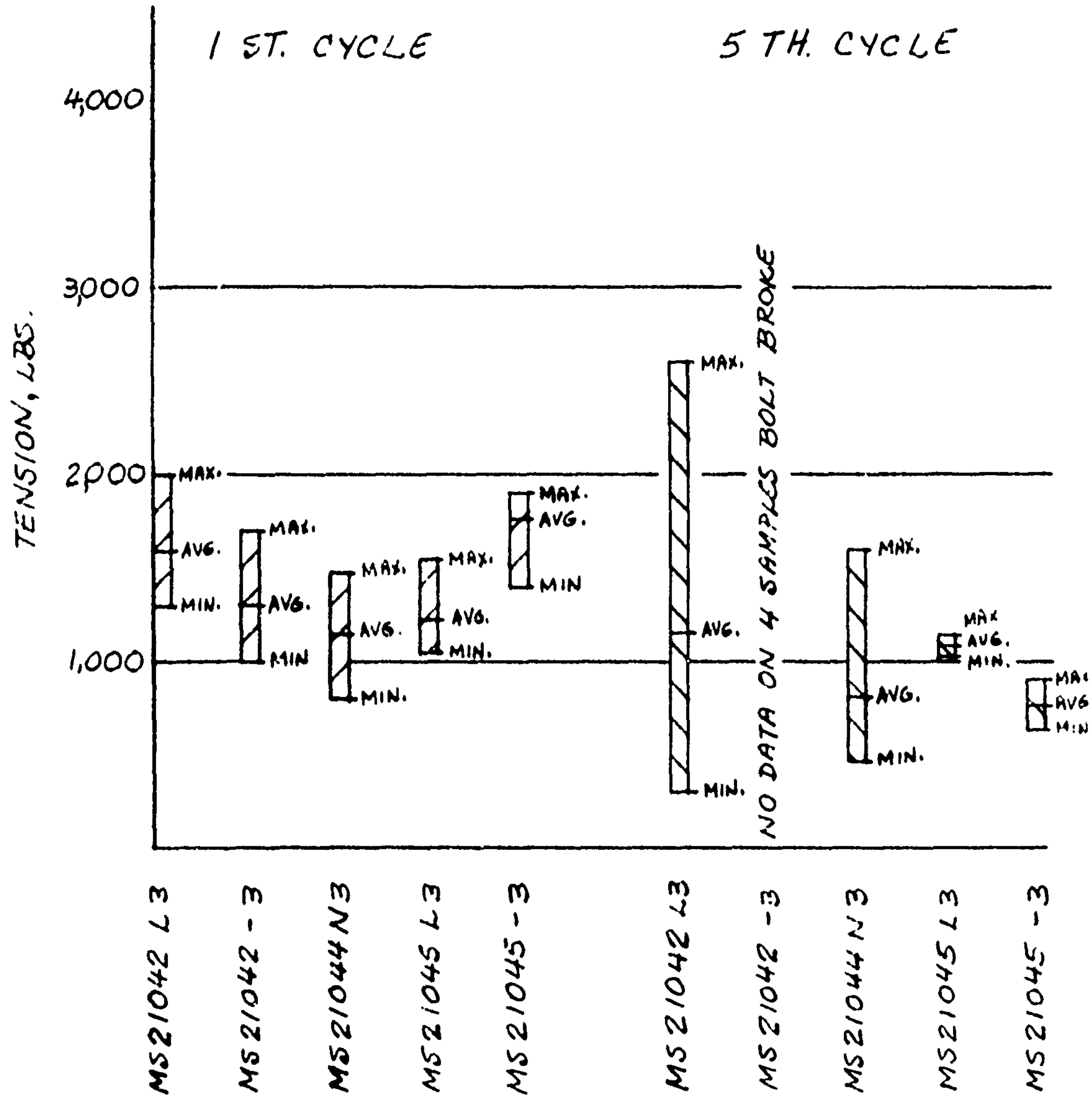

FIGURE 32. COMPARATIVE TORQUE-TENSION RELATIONSHIP FOR NO. 10 SIZE NUTS TORQUED TO 75 IN-LBS.

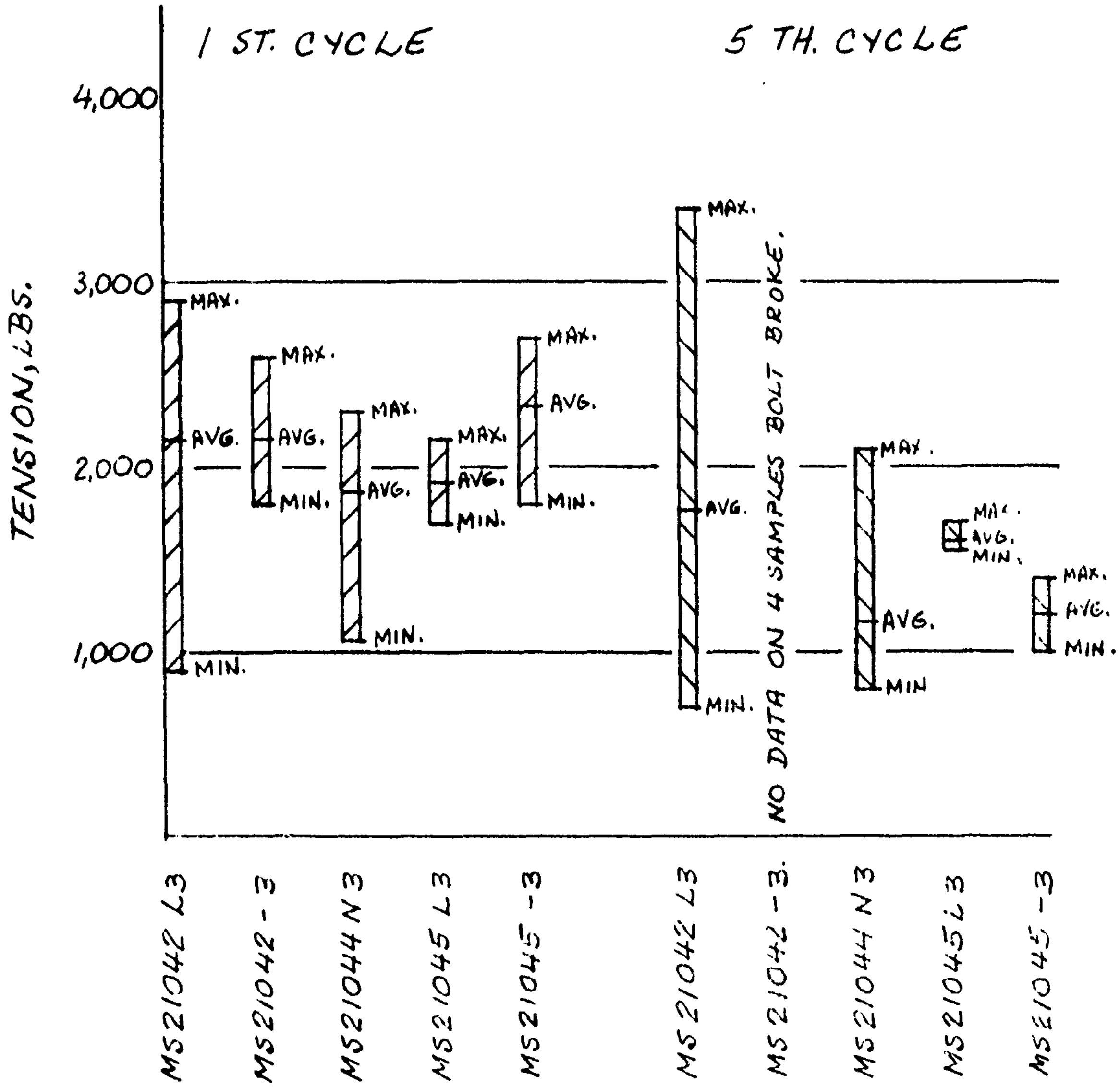

FIGURE 33. COMPARATIVE TORQUE-TENSION RELATIONSHIP FOR NO. 10 SIZE NUTS TORQUED TO 100 IN-LBS.

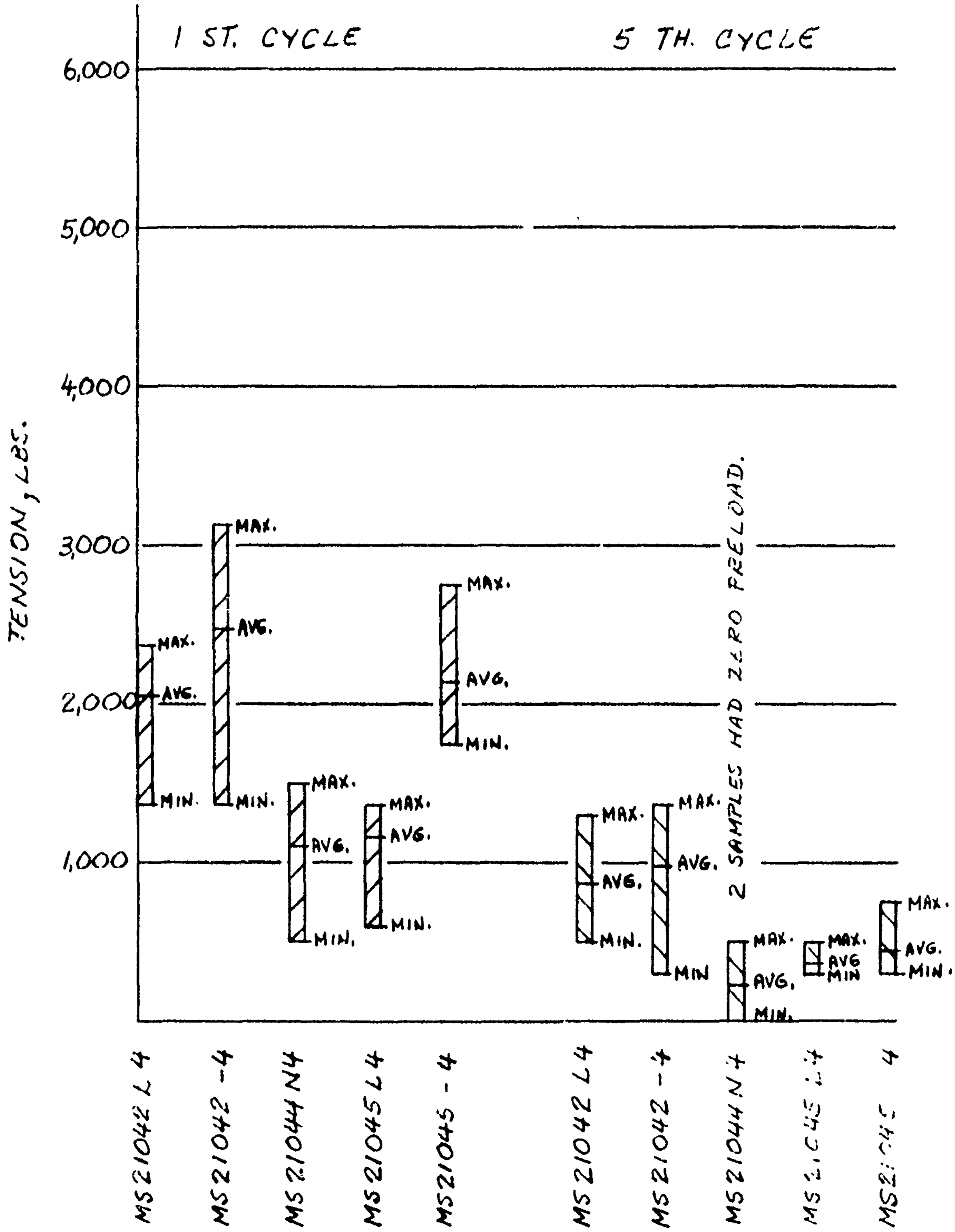

FIGURE 34. COMPARATIVE TORQUE-TENSION RELATIONSHIP FOR 1/4 SIZE NUTS TORQUED TO 100 IN-LBS.

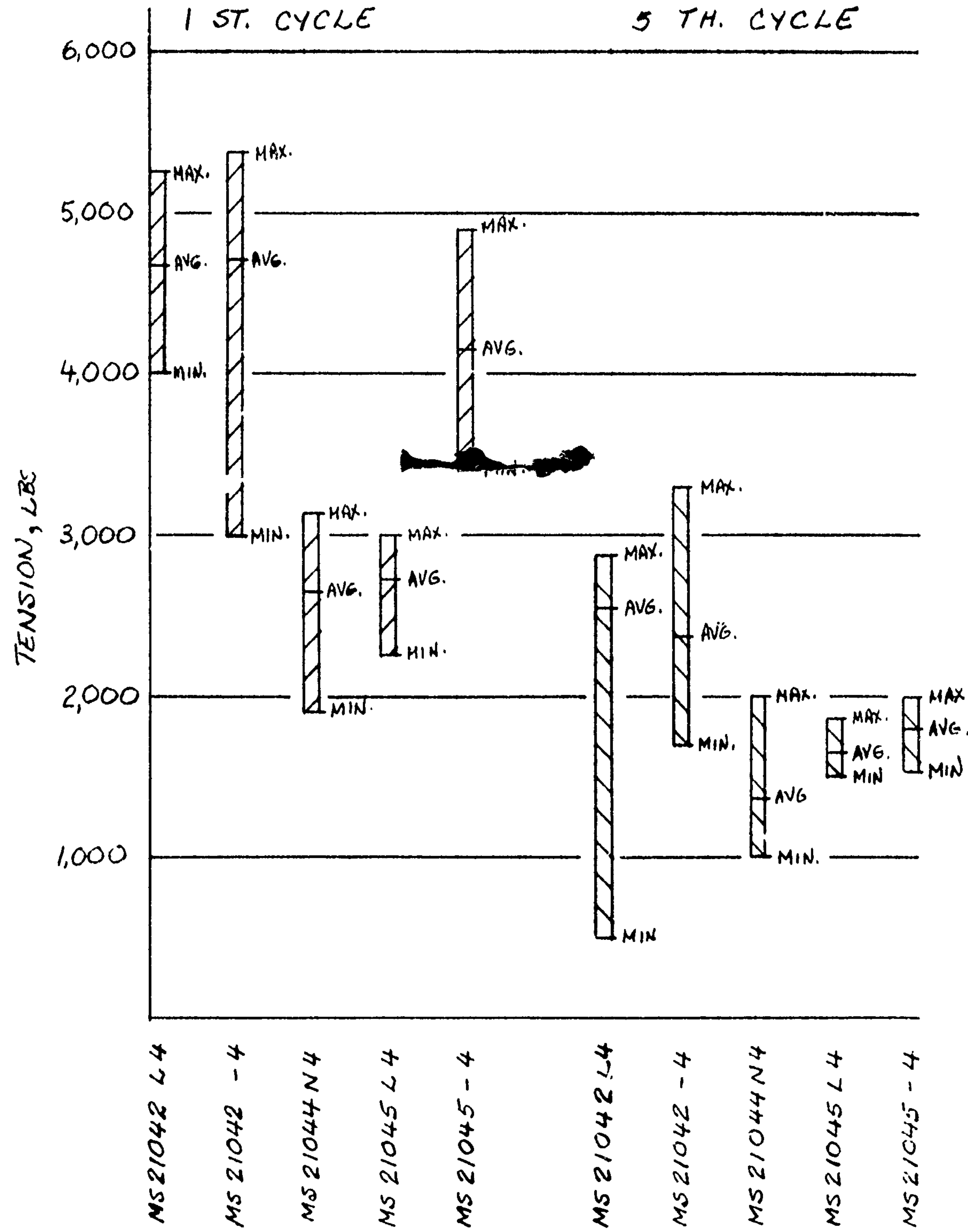

FIGURE 35. COMPARATIVE TORQUE-TENSION RELATIONSHIP FOR 1/4 SIZE NUTS TORQUED TO 200 IN-LBS.

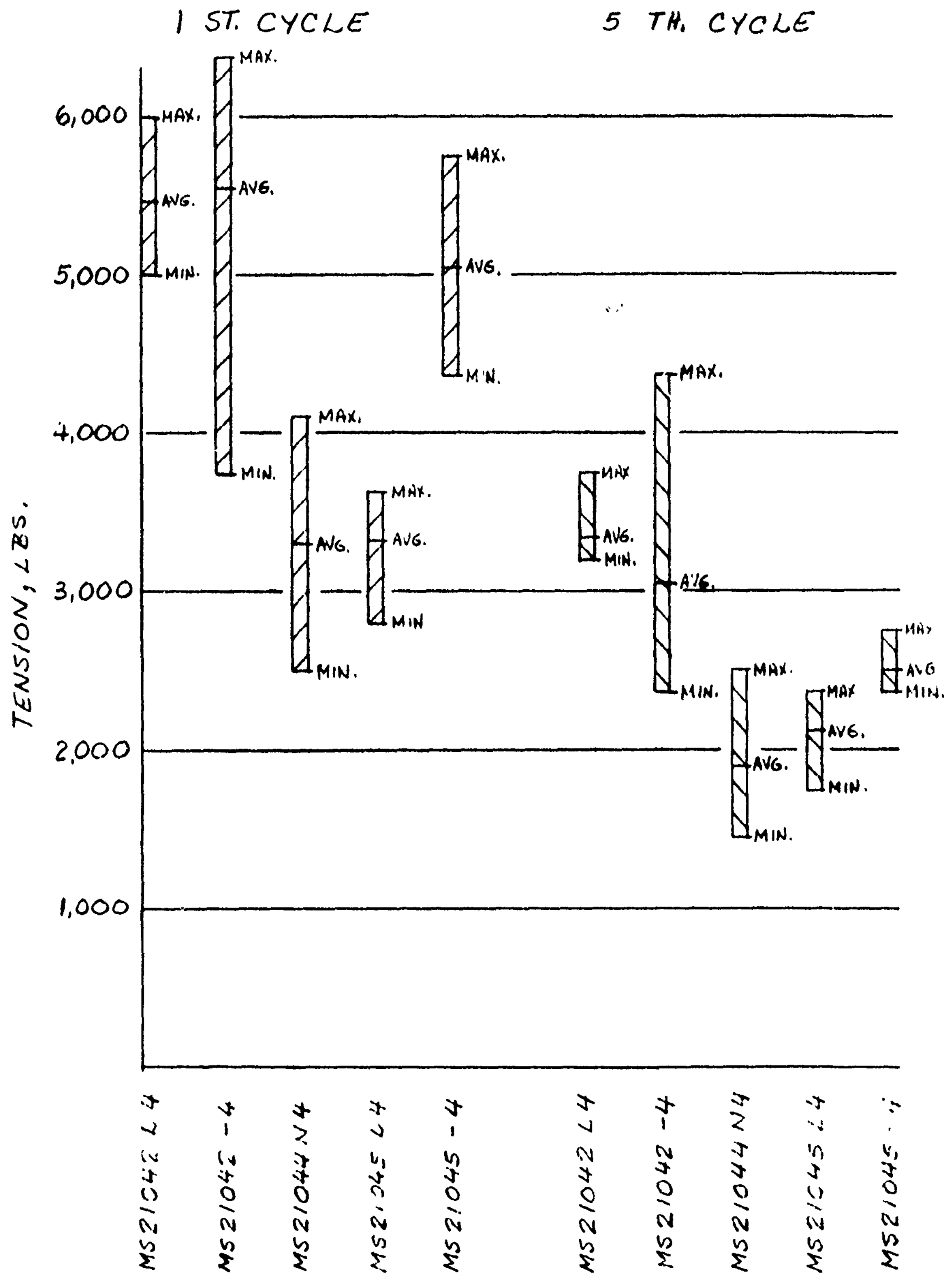

FIGURE 36. COMPARATIVE TORQUE-TENSION RELATIONSHIP FOR 1/4 SIZE NUTS TORQUED TO 250 IN·LBS.

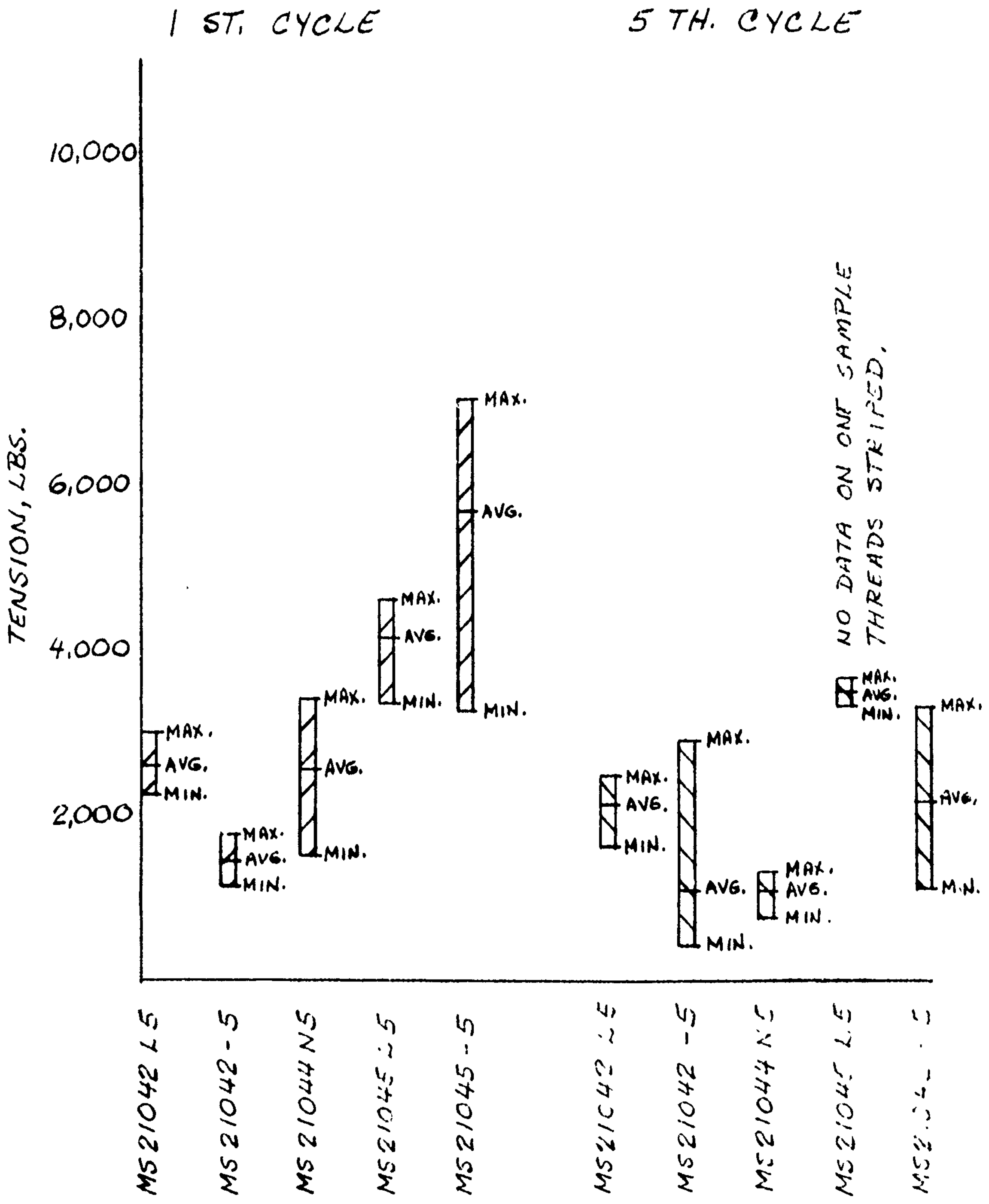

FIGURE 37. COMPARATIVE TORQUE - TENSION RELATIONSHIP FOR 5/16 SIZE NUTS TORQUED TO 200 IN LBS.

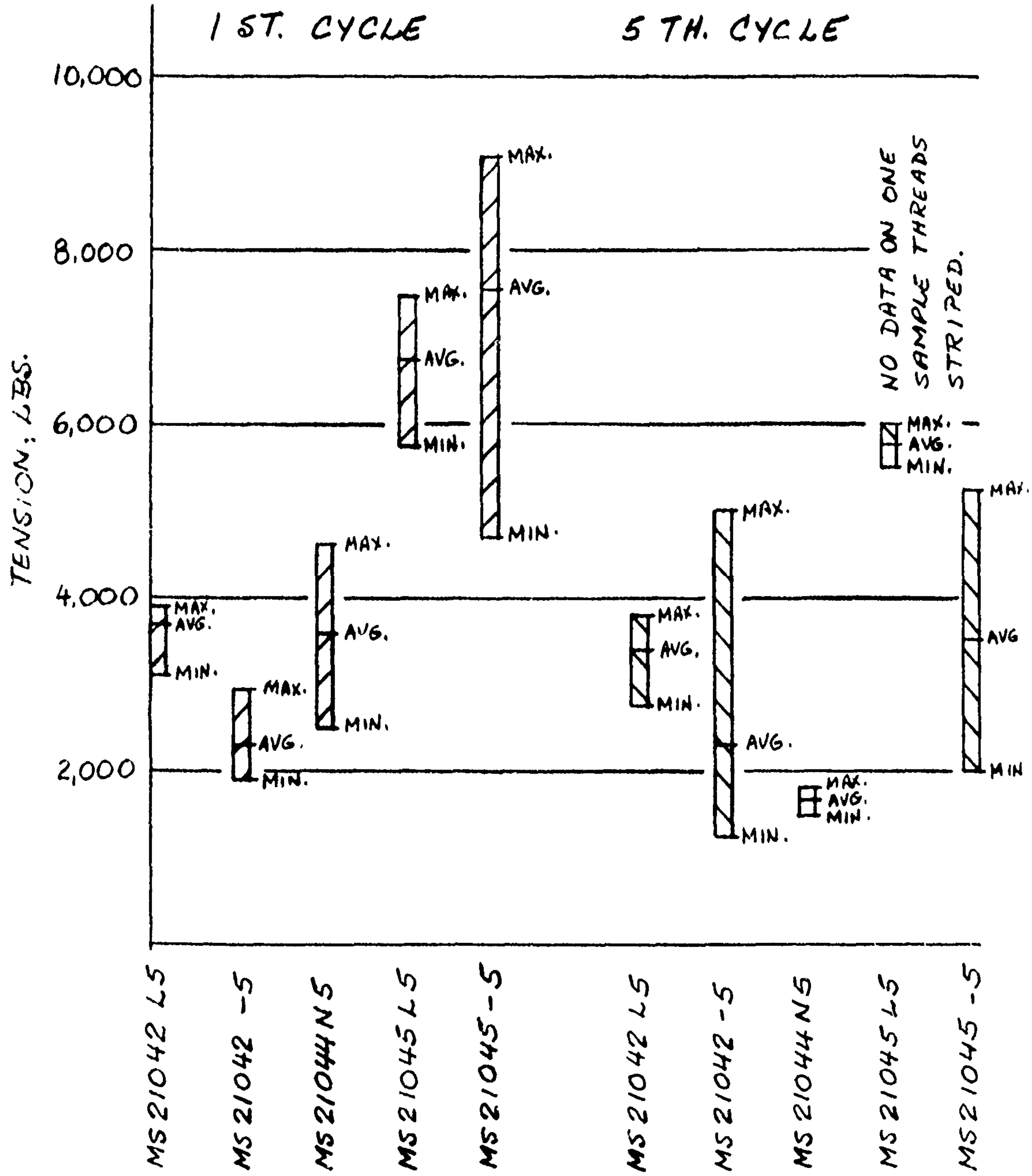

FIGURE 38. COMPARATIVE TORQUE-TENSION RELATIONSHIP FOR 5/16 SIZE NUTS TORQUED TO 300 IN-LBS.

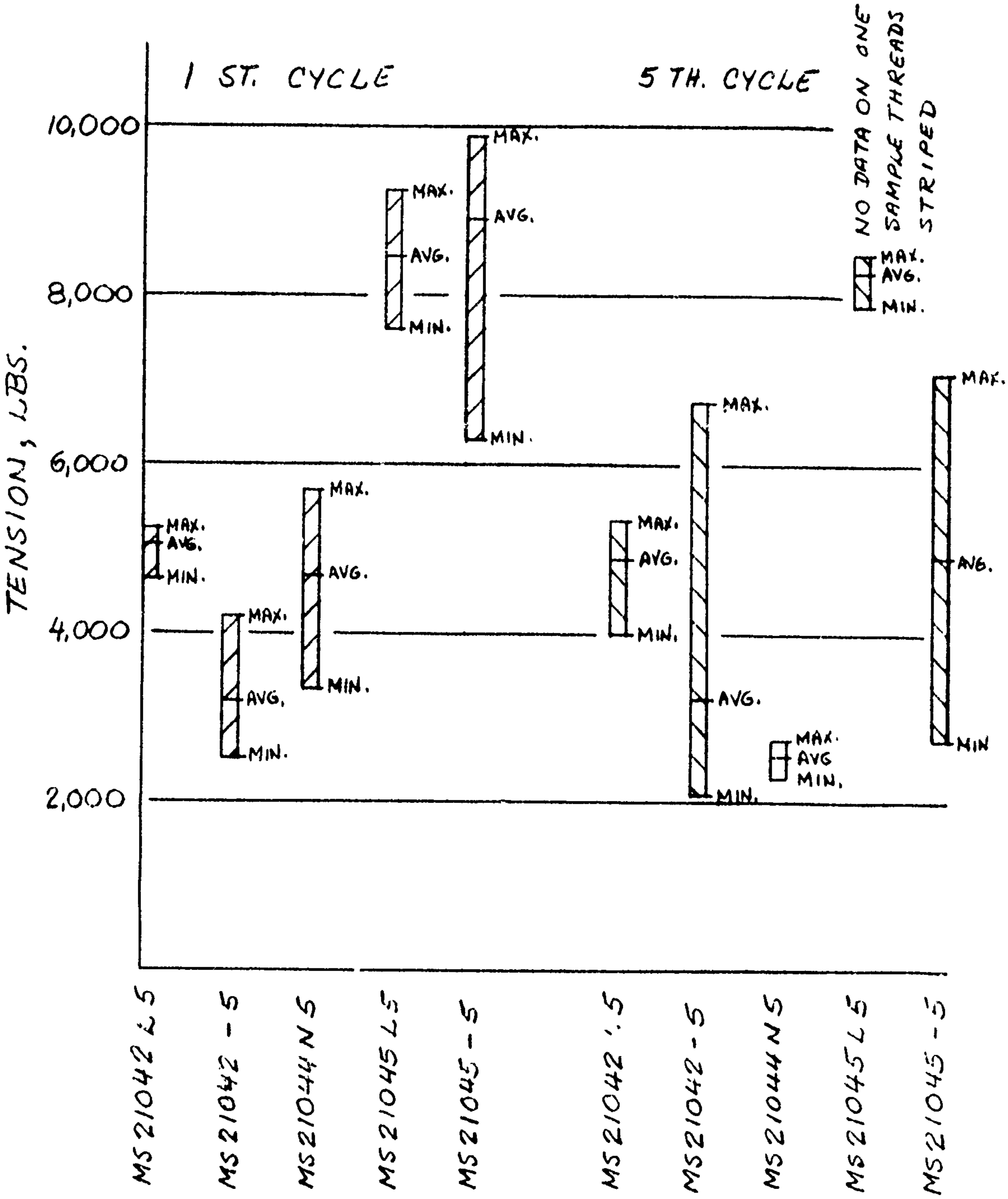

FIGURE 39. COMPARATIVE TORQUE-TENSION RELATIONSHIP FOR 5/16 SIZE NUTS TORQUED TO 400 IN-LBS.

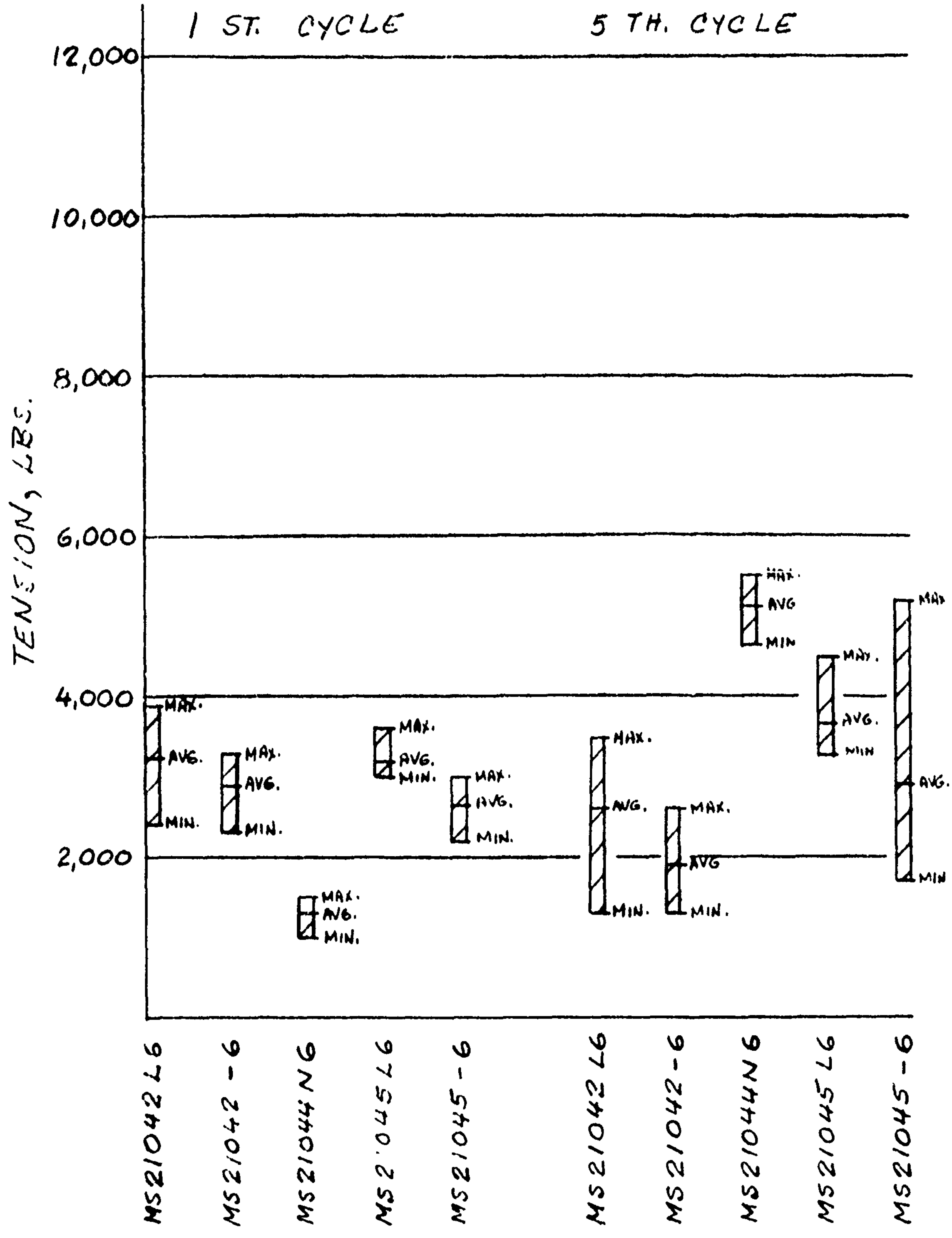

FIGURE 40. COMPARATIVE TORQUE-TENSION RELATIONSHIP FOR 3/8 SIZE NUTS TORQUED TO 200 IN-LBS.

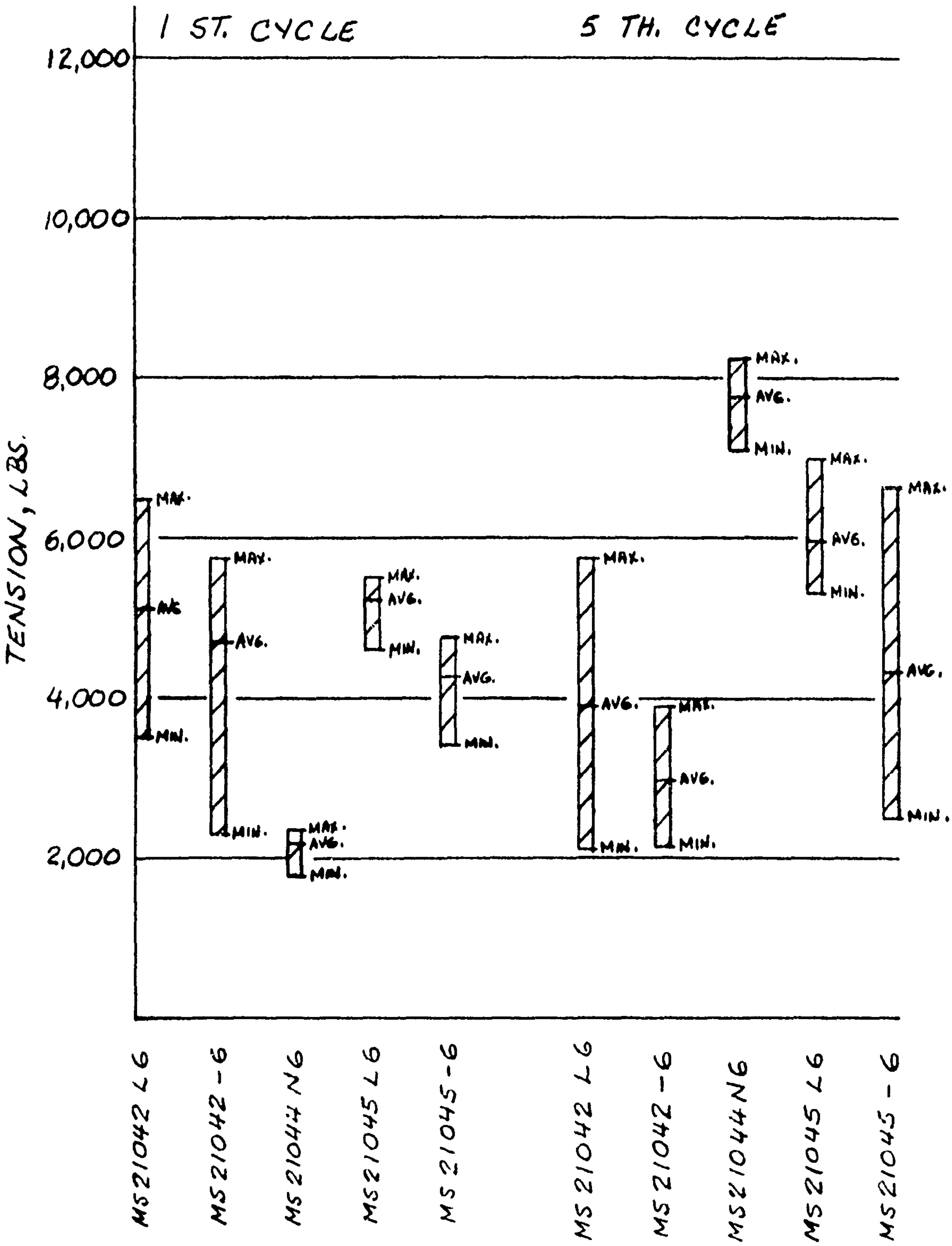

FIGURE 41. COMPARATIVE TORQUE-TENSION RELATIONSHIP FOR 3/8 SIZE NUTS TORQUED TO 300 IN-LBS.

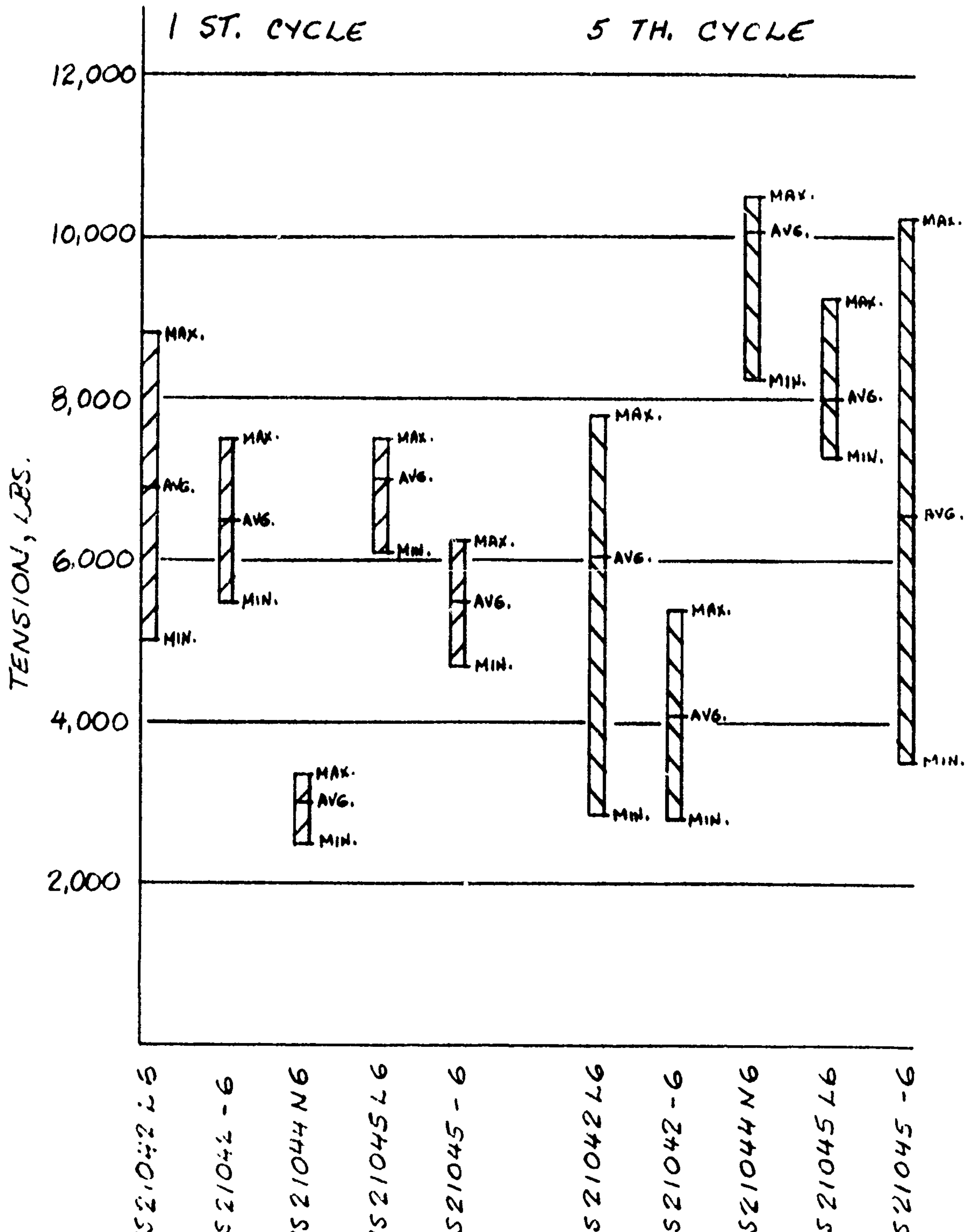

FIGURE 42. COMPARATIVE TORQUE-TENSION RELATIONSHIP FOR 3/8 SIZE NUTS TORQUED TO 400 IN-LBS.

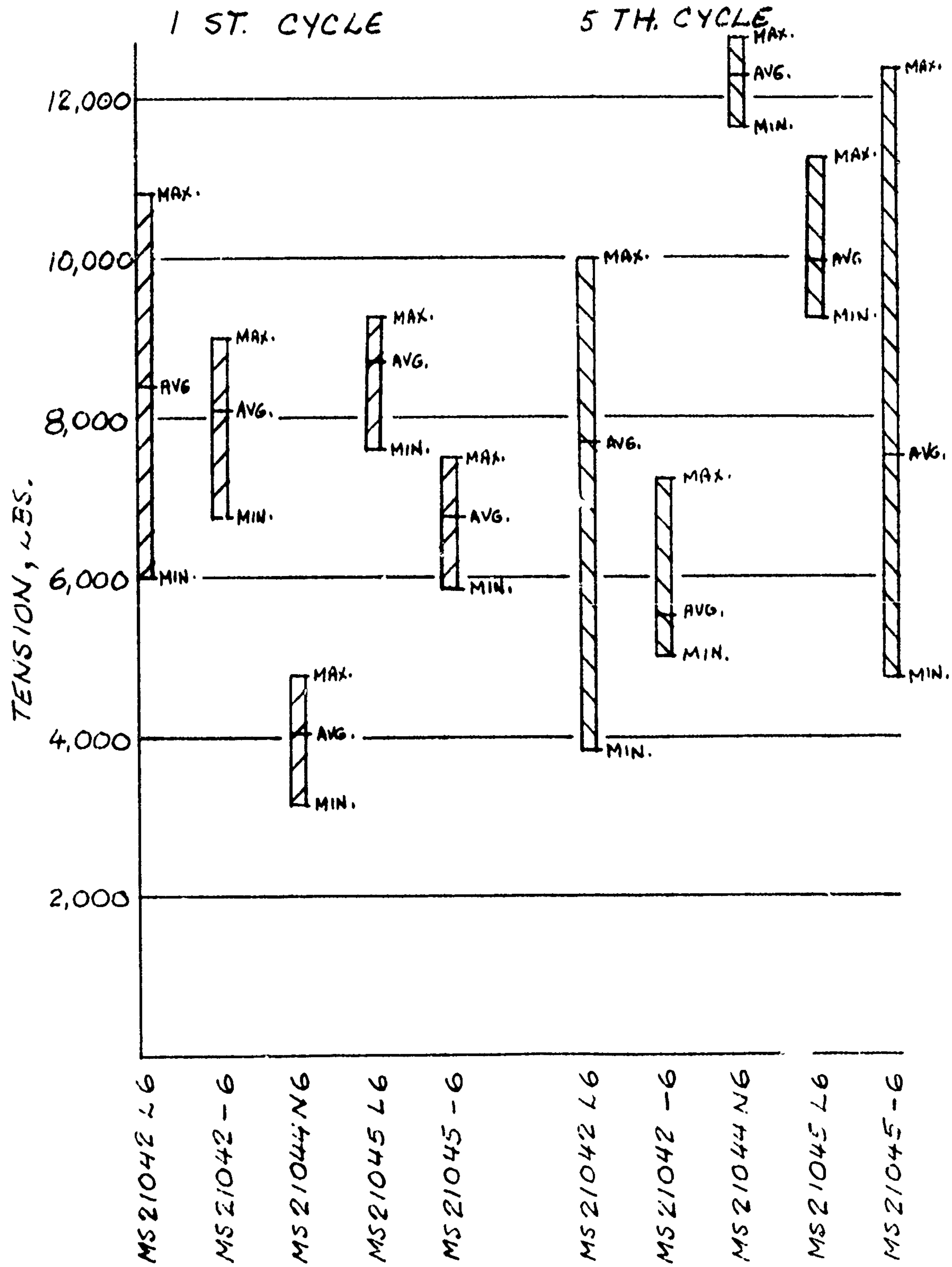

FIGURE 43. COMPARATIVE TORQUE-TENSION RELATIONSHIP FOR 3/8 SIZE NUTS TORQUED TO 500 IN-LBS.

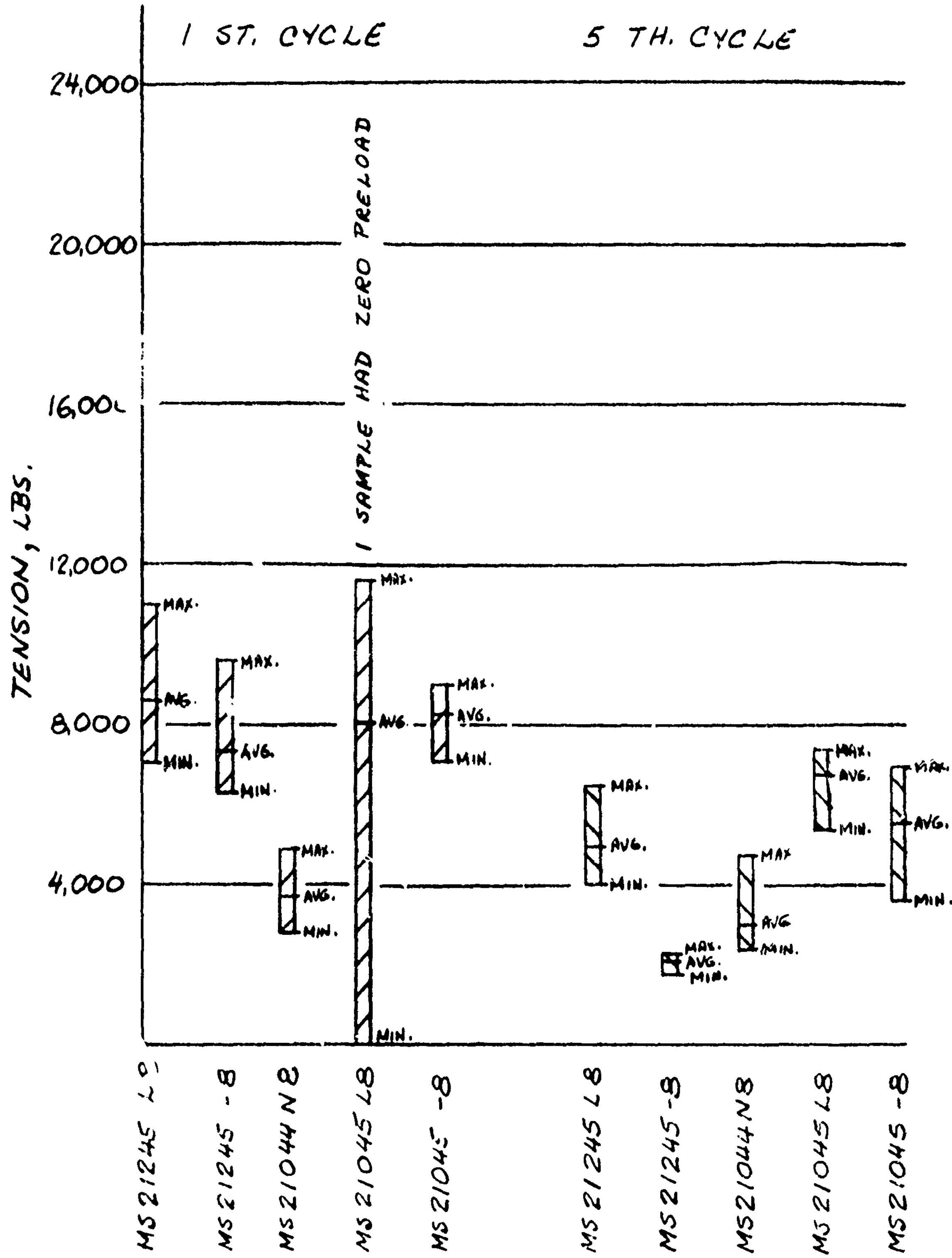

FIGURE 44. COMPARATIVE TORQUE-TENSION RELATIONSHIP FOR 1/2 SIZE NUTS TORQUED TO 50 FT-LBS

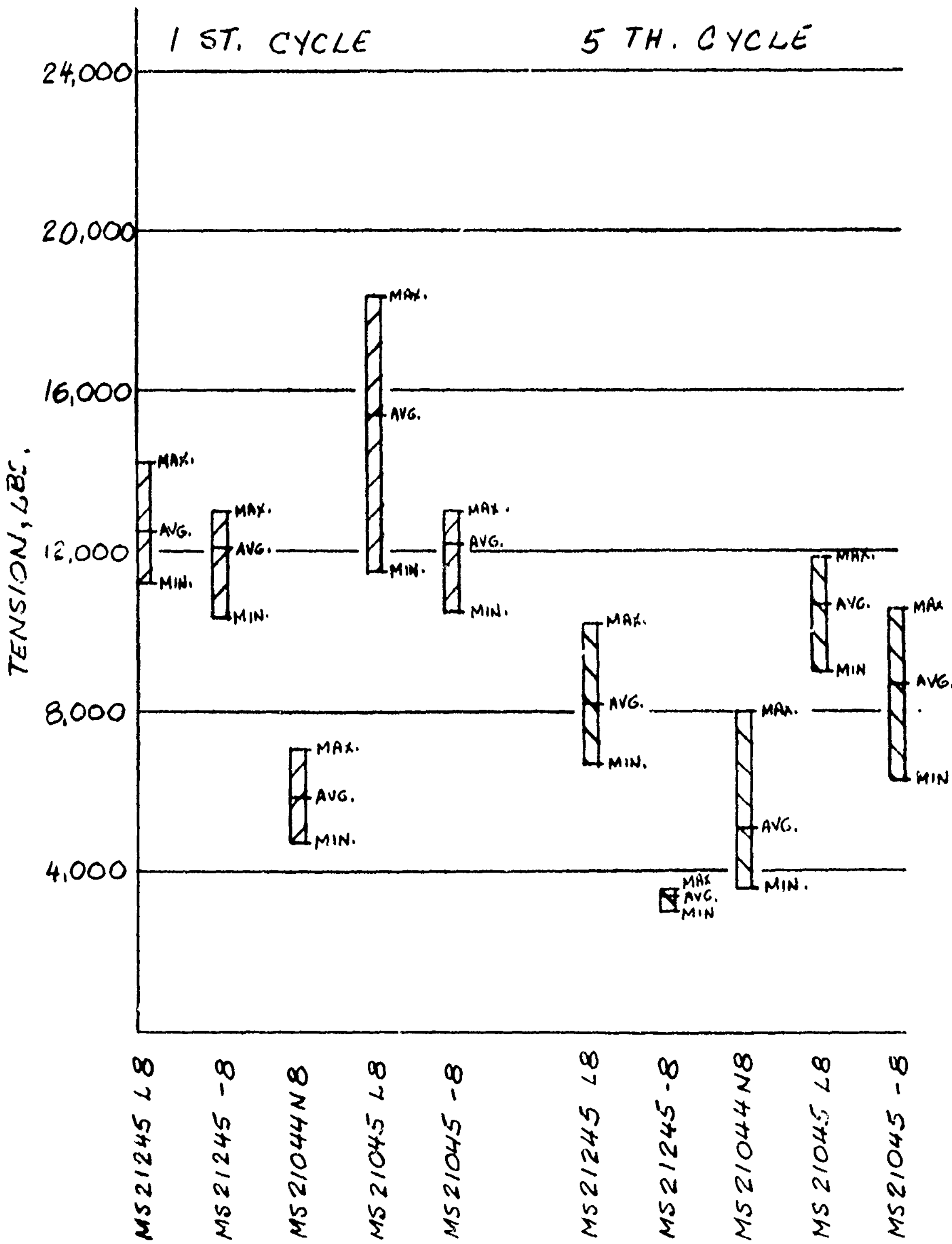

FIGURE 45. COMPARATIVE TORQUED-TENSION RELATIONSHIP FOR 1/2 SIZE NUTS TORQUED TO 75 FT-LBS.

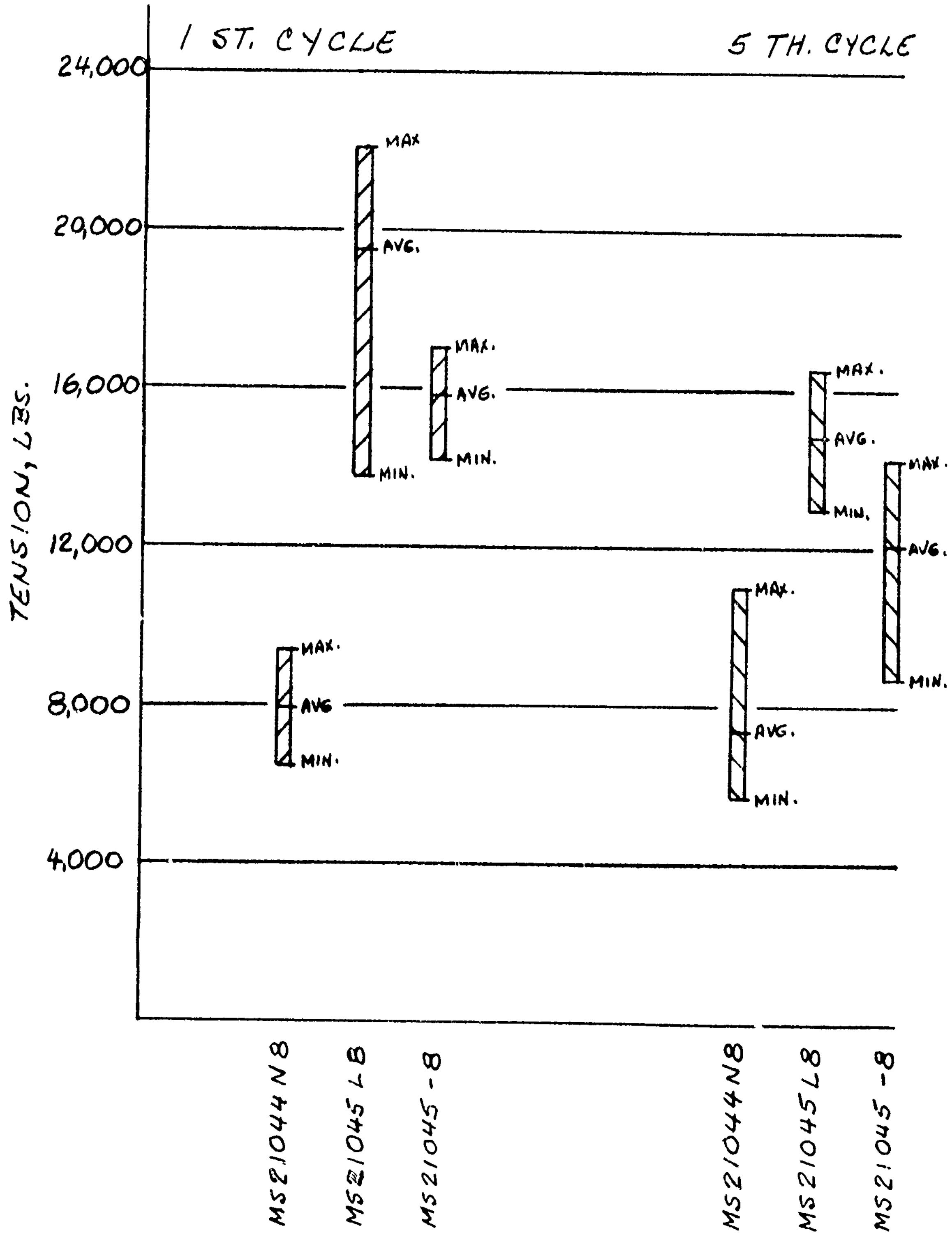

FIGURE 46. COMPARATIVE TORQUE - TENSION RELATIONSHIP FOR 1/2 SIZE NUTS TORQUED TO 100 FT-LBS.

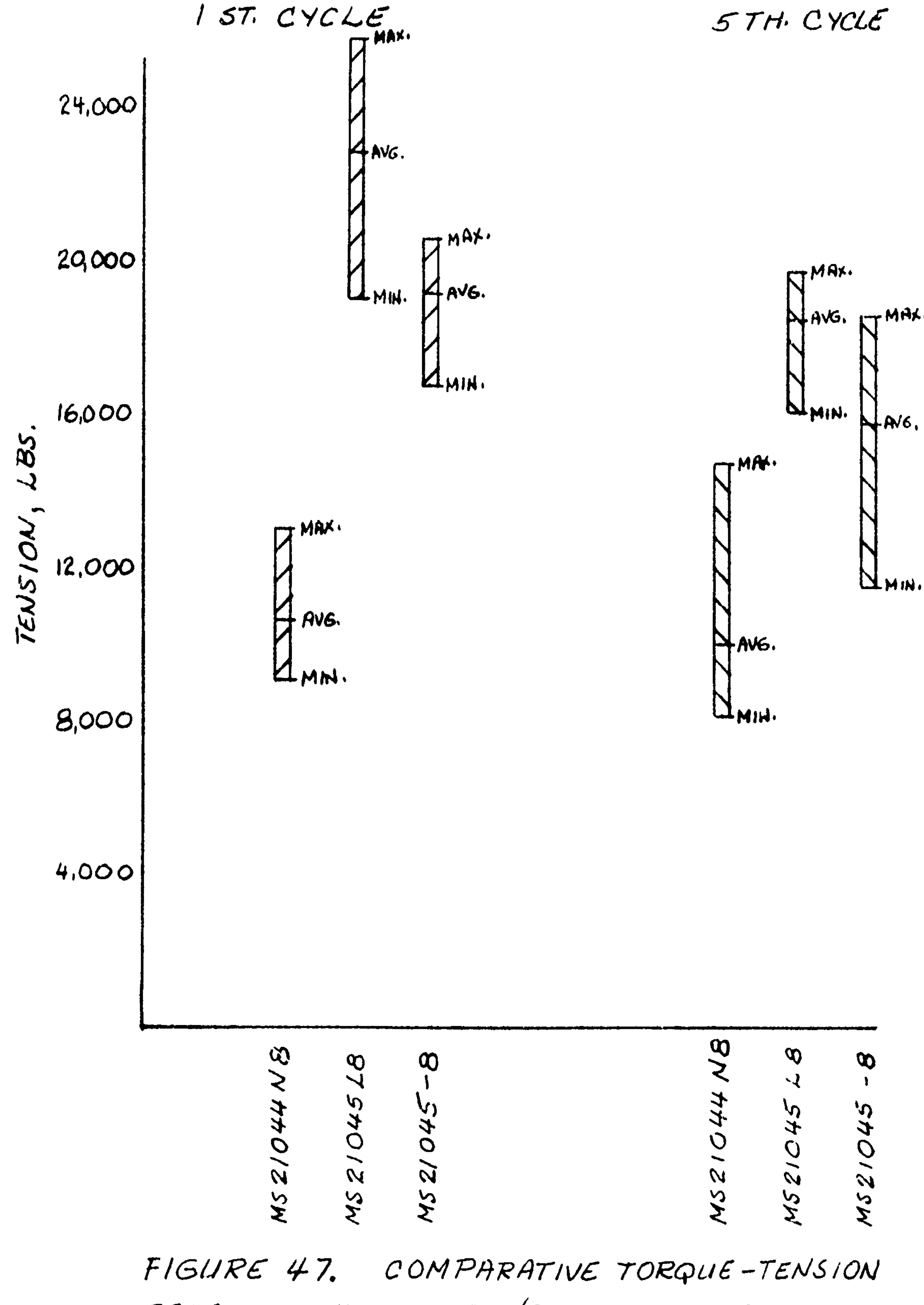

FIGURE 47. COMPARATIVE TORQUE-TENSION RELATIONSHIP FOR 1/2 SIZE NUTS TORQUED TO 125 FT-LBS.

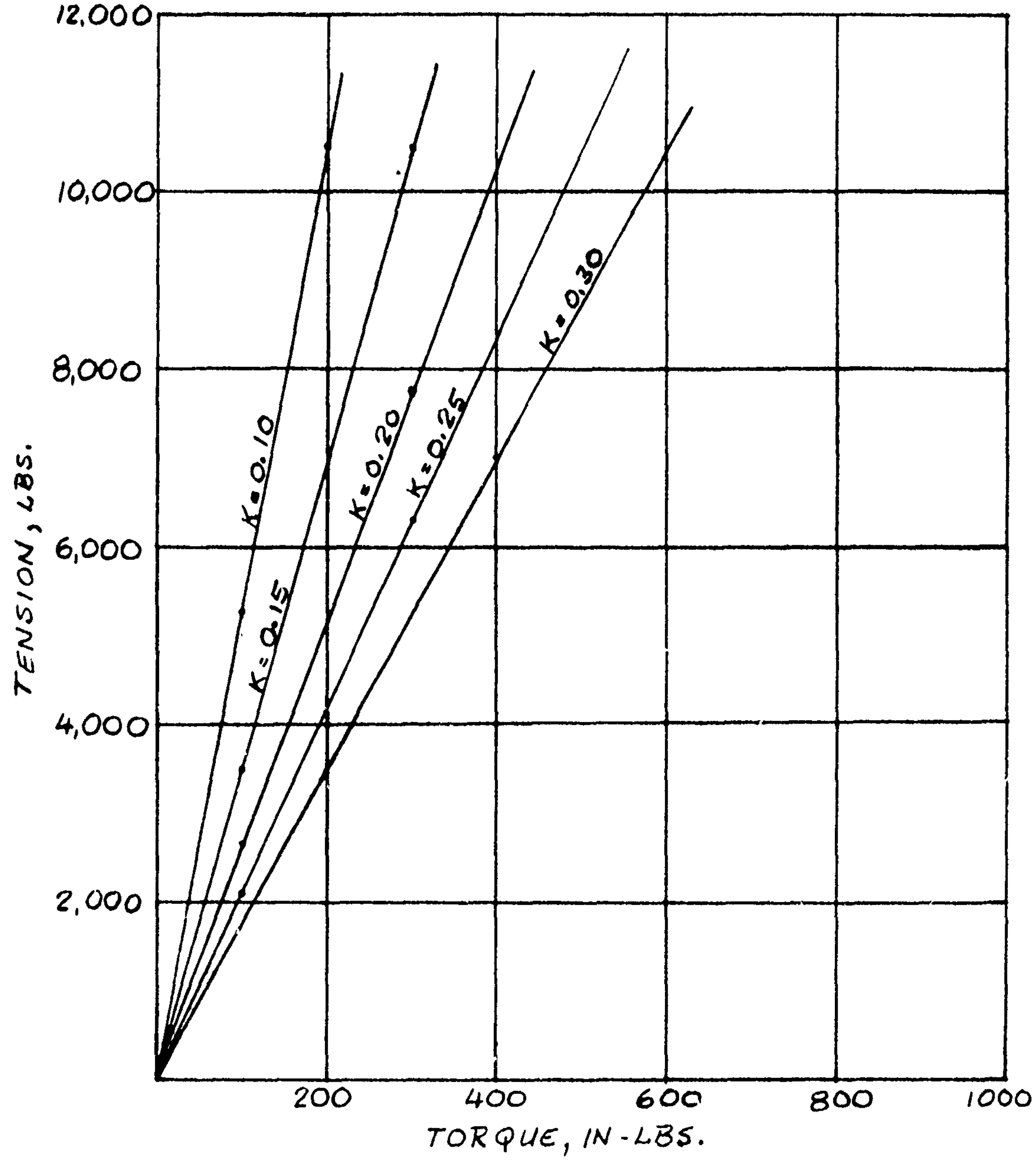

FIGURE 48. CALCULATED TORQUE-TENSION RELATIONSHIP FOR NO. 10 SIZE NUTS WITH VARIED FRICTION FACTOR.

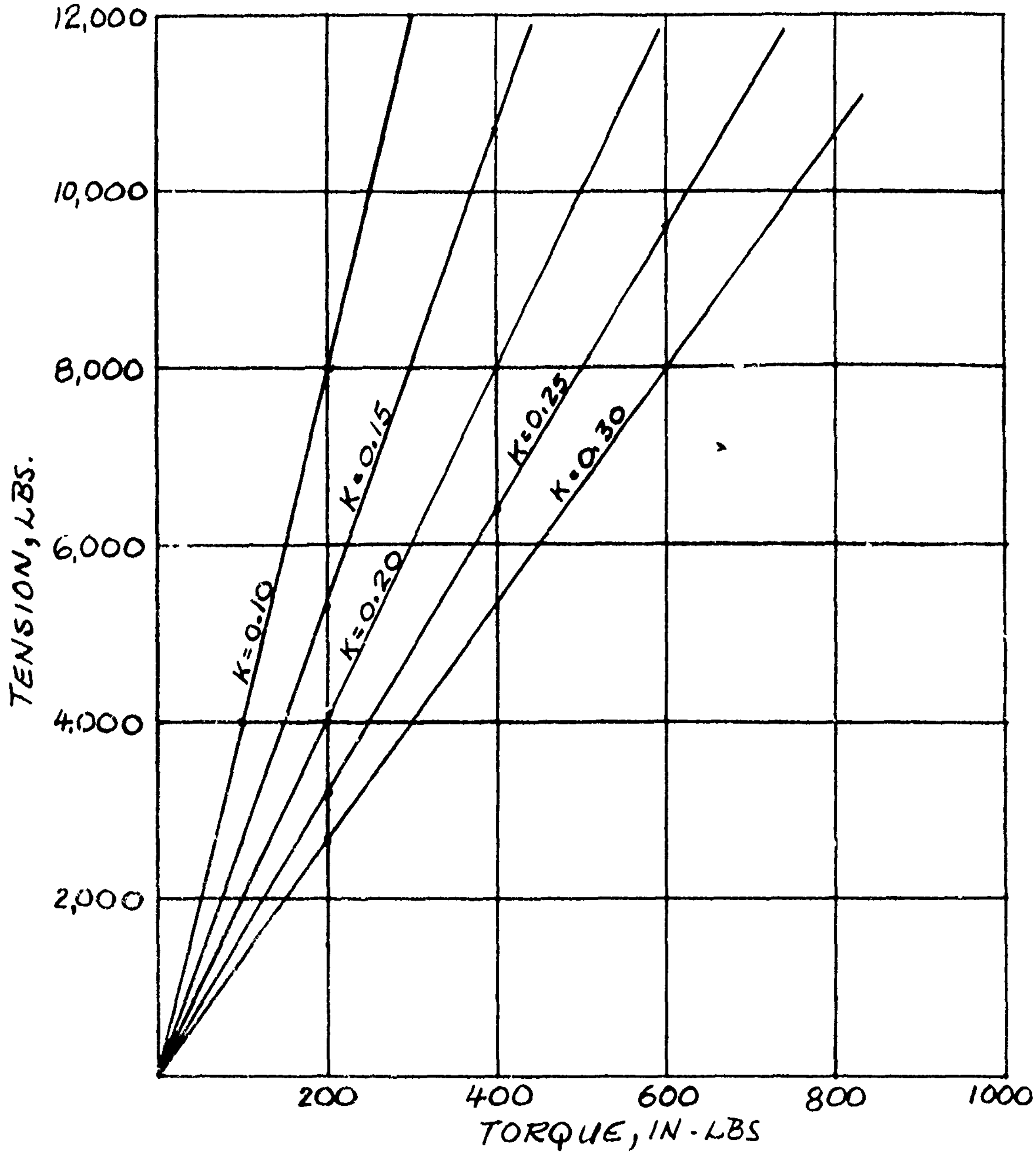

FIGURE 49. CALCULATED TORQUE-TENSION RELATIONSHIP FOR 1/4 SIZE NUTS WITH VARIED FRICTION FACTOR.

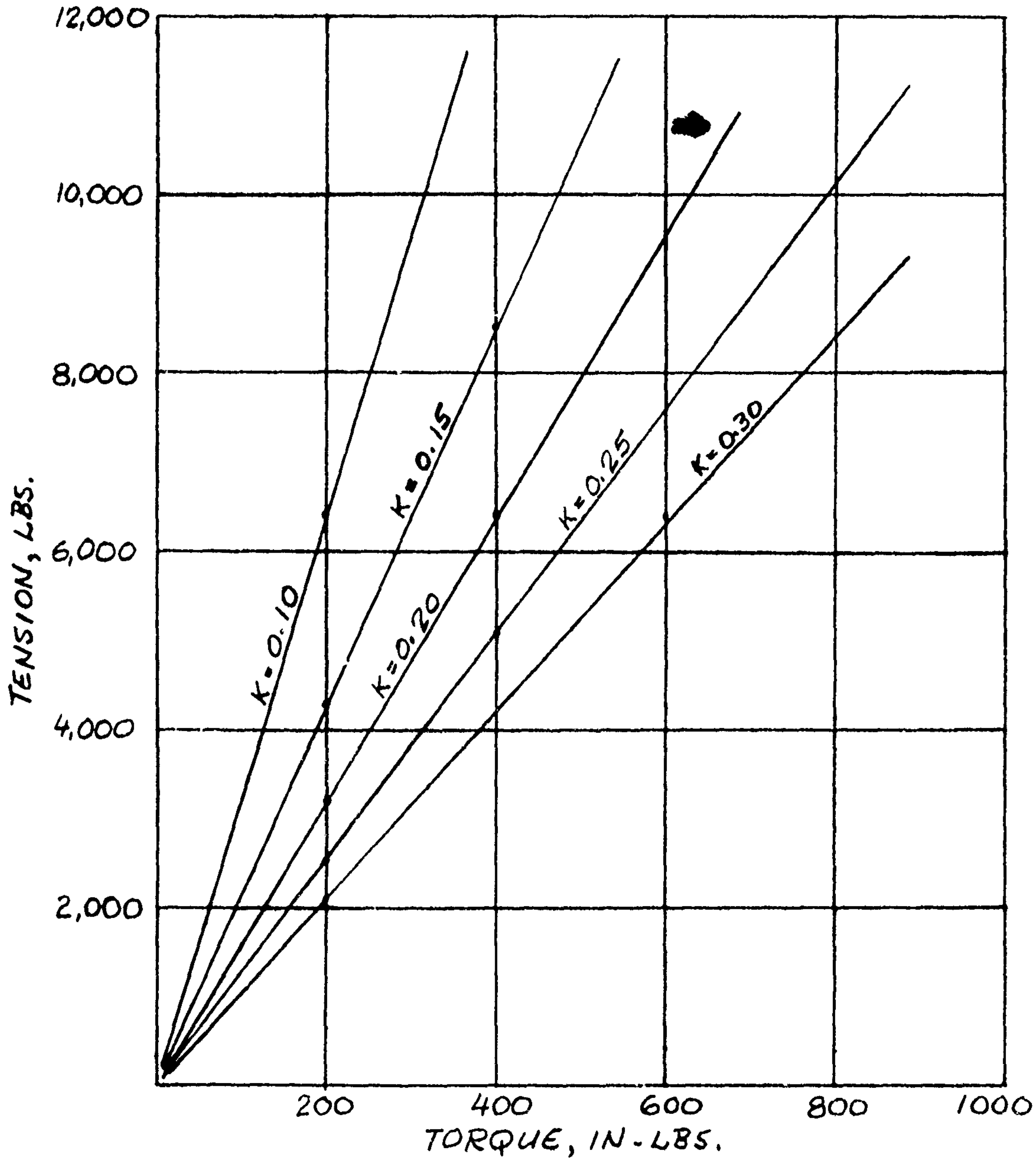

FIGURE 50. CALCULATED TORQUE-TENSION RELATIONSHIP FOR 5/16 SIZE NUTS WITH VARIED FRICTION FACTOR.

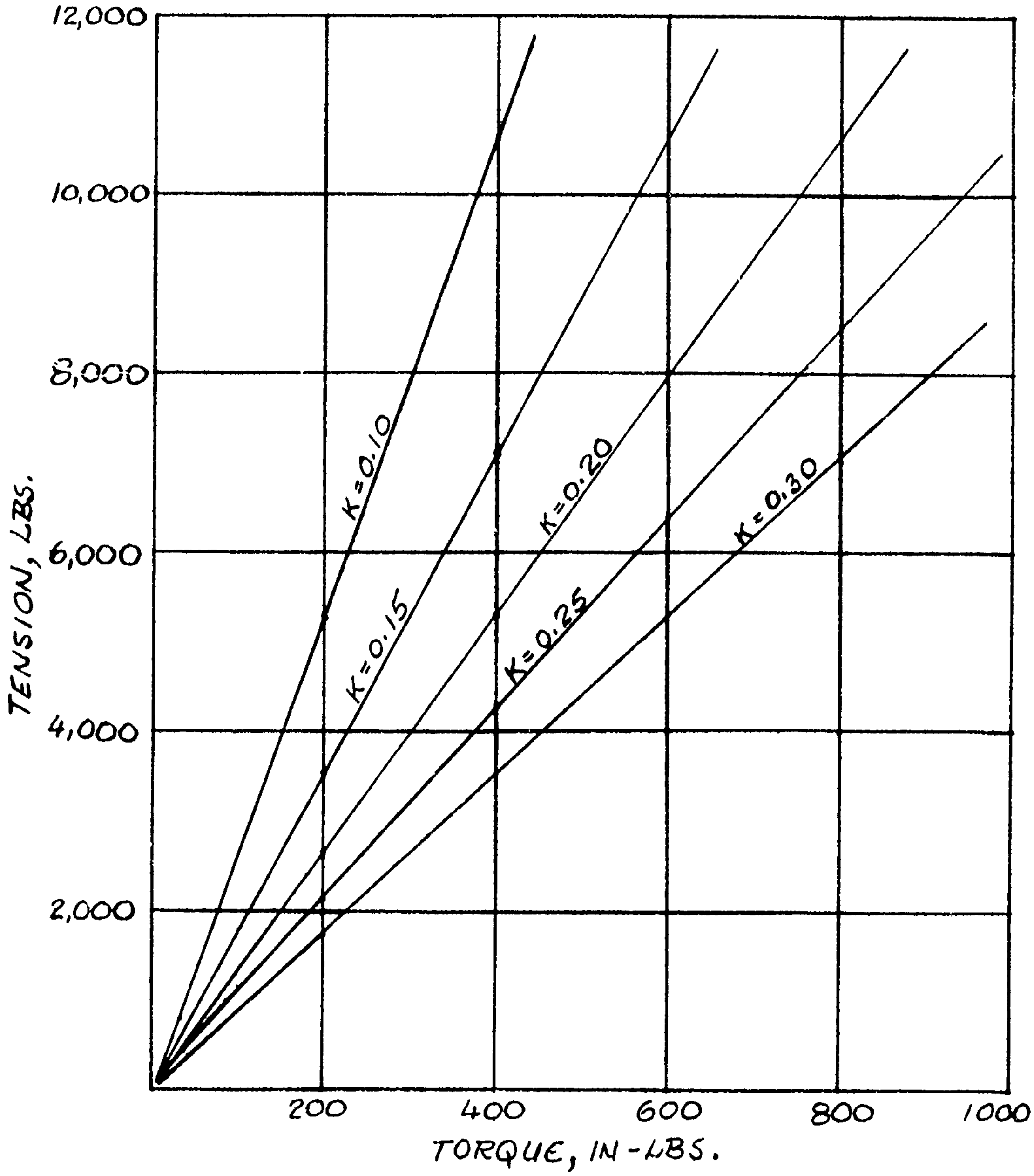

FIGURE 51. CALCULATED TORQUE-TENSION RELATIONSHIP FOR 3/8 SIZE NUTS WITH VARIED FRICTION FACTOR.

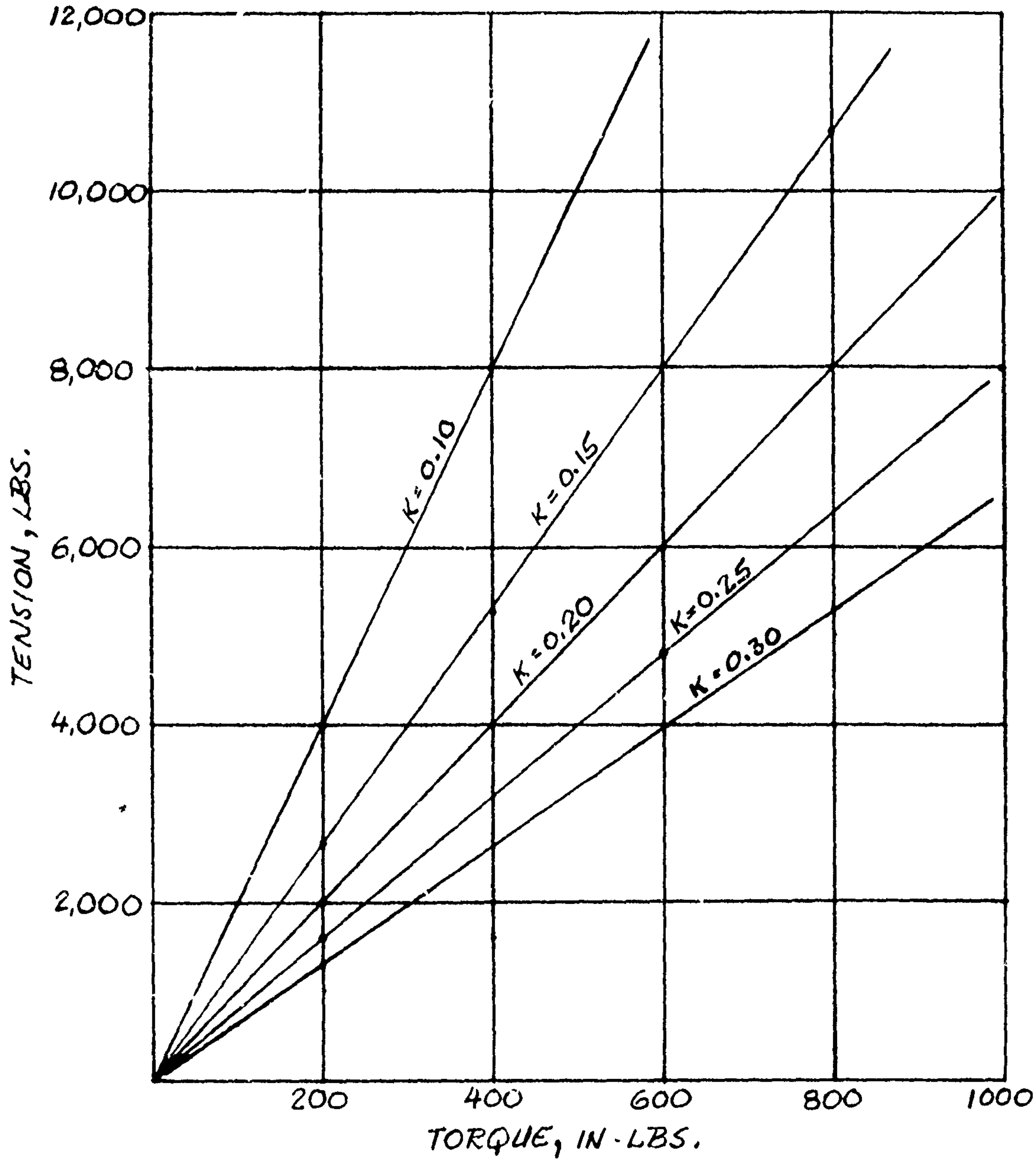

FIGURE 52. CALCULATED TORQUE-TENSION RELATIONSHIP FOR 1/2 SIZE NUTS WITH VARIED FRICTION FACTOR.

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